REDUCING EU CATTLE NUMBERS TO REACH GREENHOUSE GAS TARGETS

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Cattle are directly responsible for half of the greenhouse gas (GHG) emissions from EU agriculture, once enteric fermentation and manure management are taken into account. Faced with the need to achieve a rapid curbing of GHG, voices in some EU circles have been calling for reducing the size of cattle herds, a radical option whose impact has not even been roughly estimated. As a working assumption, this paper first analyses the decrease of EU cattle numbers required to achieve 30% of the GHG reduction targets in agriculture for 2030. Based on the Effort Sharing Regulation (ESR), the corresponding decrease in EU cattle numbers would be 16.3 million head, a 22% reduction compared to 2022. We then discuss the implications of such a downsizing for trade and beef consumption within the EU, taking stock of current data and formulating some assumptions about supply and demand behaviour. Finally, we briefly consider other mitigation measures less radical than downsizing.

Key Words: Greenhouse Gas, Methane, Cattle, Agriculture, Farming Systems, International trade, European Green Deal.

1. The author is very grateful to two anonymous referees for their helpful comments on an earlier version of this article. Any omissions or errors remain the responsibility of the author.

1. Introduction

Launched in December 2019, the European Green Deal (EGD) is a European Union (EU) initiative that aims at making Europe the first carbon-neutral continent by 2050, in order to keep global warming below 2°C above pre-industrial levels. As an interim target, the EU as a whole must reduce its greenhouse gas (GHG) emissions by at least 55% below 1990 levels by 2030. This will require efforts from all EU countries and sectors. In this context, the EU agriculture sector faces specific challenges. It has to set out on the path towards sustainable food systems, while at the same time securing food for its 450 million inhabitants. This will necessarily entail changes in agricultural practices and production models as well as in food consumption patterns. To deliver on the EGD in the agricultural sector, several options, often complementary, are on the table, ranging from the application of agro-ecological principles to the fight against food waste, including a shift in agricultural production. To date, most assessments of EGD have focused on reducing the use of fertilisers and pesticides, sometimes in association with changes in diet.[2] In this article, we explore another option that is gaining momentum in some circles, and for which we do not even have rough evidence of its impact: decreasing the numbers of EU cattle. Our simulation exercise, based on simple assumptions, is intended to contribute to the debate on the involvement of the agricultural sector in climate change mitigation and to assess the impact this would have on EU citizens' beef consumption.

In 2021, agriculture accounted for 10.7% of EU GHG emissions (Table 1), mainly due to methane (61% of emissions) and nitrous oxide (36%). Compared to other sectors, agriculture's carbon dioxide emissions are very low (3% compared to 81% for the economy as a whole). All this gives the sector specific characteristics in terms of GHG emissions and therefore the policy responses required as well. As argued by Cooper *et al.* (2013), "despite their relatively small share in total emissions, addressing methane and nitrous dioxide emissions, including those from agriculture, is important for the efficient functioning of a multi-gas mitigation strategy".

The specificity of agriculture becomes more apparent when the characteristics of methane (CH_4) and nitrous oxide (N_2O) are

2. See for example Guyomard *et al.* (2023) in this Special Issue.

compared with those of carbon dioxide (CO_2). In terms of global warming potential, measured as the "ability of 1 kg of each gas to trap heat over 100 years", methane has a potential 21-36 times greater than CO_2, and nitrous oxide 265-310 times greater (Mielcarek-Bocheńska and Rzeźnik, 2021). Moreover, the lifetime of different gases in the atmosphere varies dramatically. Carbon dioxide does not break down easily and remains in the atmosphere for several centuries, nitrous oxide for about 121 years and methane for about 12 years. Finally, in addition to its role in global warming, N_2O is also responsible for ozone depletion and eutrophication. While the first problem is almost solved, the second is gaining momentum due to over-application of manure and the resulting losses that contaminate water and cause green algae.

Cattle livestock make a large contribution to CH_4 and N_2O emissions. Methane is predominantly emitted through enteric fermentation, and due to the particularities of their digestive tract (rumen) cattle emit a lot of methane compared to monogastric (non-ruminant) animals such as pigs or poultry. In 2021, cattle accounted for 85% of enteric fermentation (Figure 1A), which in turn accounted for 48% of total agricultural GHG emissions (Table 2). Manure management (urine and faeces) is another source of GHG emissions (accounting for 17% of total agricultural GHG emissions) and is responsible for additional methane emissions as well as for nitrous oxide emissions. Again, cattle make a major contribution to manure management, accounting for 45% (Figure 1B). Altogether, 49% of GHG emissions in EU agriculture came

Table 1. **EU GHG emissions (agriculture versus total economy)**

	Share of agriculture in total GHG emissions (EU, 2021)	Sectoral emissions by type of gas (EU, 2021)	
		Total economy	Agriculture
All gases	10.7%	100%	100%
Carbon dioxide CO_2	0.3%	81%	3%
Methane CH_4*	57.7%	11%	61%
Nitrous oxide NO_2*	78.0%	5%	36%
Other gases*	0.0%	2%	0%

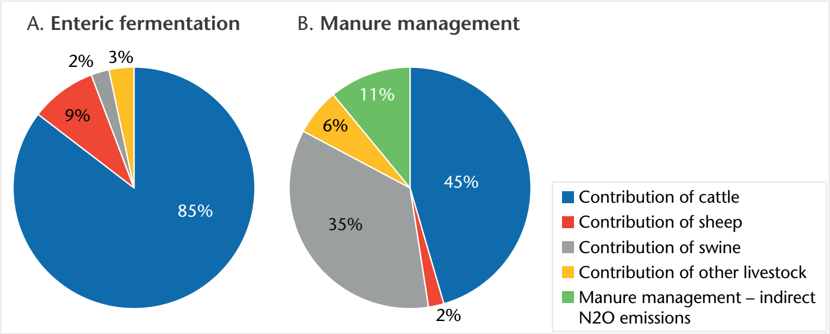
Eurostat; computations of the author.

* Emissions are expressed in CO_2-equivalent, taking into account a global warming potential for CH_4 and N_2O of, respectively, 28 et 265 (values used by Eurostat).

Lecture grid: 57.7% of EU methane emissions come from agriculture. Of all greenhouse gas emissions from agriculture, methane accounts for 61%.

directly from cattle in 2021.[3] More generally, cattle are recognised as a major contributor to global GHG emissions in both developed and developing countries (FAO, 2023).

Figure 1. **Contribution of livestock to direct GHG emissions (equiv. CO_2, in 2021)***



Eurostat; computations of the author.

* Equivalent CO_2: coefficients of 28 for methane (contained in enteric fermentation and manure management) and coefficients of 265 for nitrous oxide (contained in manure management).

Table 2. **GHG emissions by source in the EU agricultural sector (in 2021)**

	In million tonnes, CO_2 equivalent	Emissions by source (in %)
Total	378.4	100%
Enteric fermentation	182.5	48%
Manure management	62.9	17%
Managed agricultural soils*	118.0	31%
Others**	15.0	4%

Eurostat; computations of the author.

*GHG emissions as a consequence of, mainly, increased application of synthetic nitrogen (N) fertilizer and manure.
**GHG emissions from rice cultivation, field burning of residues, liming, urea application, other carbon-containing fertilizers and other agriculture.

In this context, voices have echoed around the world to reduce cattle livestock numbers (Garnett, 2009; Thorpe, 2009). For example, Garnett (2009) argues that, due to our incapacity to substantially reduce livestock emissions through technological measures alone, a reduction in livestock and consumption is additionally required. Within the EU, the government of Ireland citing the need to meet climate change targets, has proposed cutting dairy herds by 10% over three

3. Indirect GHG emissions from cattle come from feed production and conversion of forest into pasture (Pishgar-Komleh and Beldman, 2022). These are out of the scope of this paper.

years, equivalent to the culling of 200,000 animals by 2026. In the Netherlands, which is caught up in the nitrogen crisis, the government will spend €1.47 billion to buy out cattle and reduce the country's numbers, with the ultimate goal of achieving a 30% reduction in livestock by 2030. In France, the Court of Auditors has called on the government to downsize numbers by 2 million by 2035 (and 3.5 million by 2050), arguing that "the balance sheet of cattle is unfavourable" (…) "carbon sequestration by the meadows where the animals graze is far from offsetting the emissions from livestock farming" (Cour des Comptes, 2023). Among civil society, NGOs and scientists, another argument in favour of reducing livestock is linked to a healthier diet (i.e. a diet with less protein of animal origin and more protein of plant origin). People in rich countries, particularly, are considered to eat too much meat, especially beef, which leads to chronic diseases such as diabetes, cardiovascular disease and certain cancers.[4]

In this article, we analyse the downsizing of EU cattle herds in order to reach a certain level (say, 30%) of GHG emissions reductions targeted by 2030 in agriculture. For each EU country, we take into account emissions emanating from enteric fermentation and manure management. To date, GHG emissions in livestock have been mainly investigated from enteric fermentation. The main rationale for this is based on the attractiveness of methane for rapid GHG mitigation due to its shorter lifetime (almost within a decade) than CO_2, as the bulk of methane is contained in enteric fermentation (Vermorel *et al.*, 2008; Mielcarek-Bocheńska and Rzeźnik, 2021; Beauchemin *et al.*, 2020). There is, however, no reason *per se* to not take into account manure management (Philippe and Nicks, 2014). As this would yield more accurate measures of direct GHG emissions from cattle, including because mitigation of CH_4 emissions from manure management may come at the cost of higher N_2O emissions, it makes sense to study the emissions of both gases (Philippe and Nicks, 2015; Rivera and Chará, 2021).

The rest of the article is structured as follows. In Section 2, we present the current level of GHG emissions in EU agriculture and the targets set for 2030, as defined in the Effort Sharing Regulation. This

4. A healthy diet is defined as a diet that is high in fruits, vegetables, whole grains, low and non-fat dairy and lean protein. Other characteristics of healthy dietary patterns are that they are low in saturated fat, trans fat, sodium and added sugars. See the recommendations of the World Health Organization (2020) for reaching a healthy diet: https://www.who.int/news-room/fact-sheets/detail/healthy-diet

sets numerical values for GHG emissions to be achieved in agriculture by 2030 for each EU country. In Section 3, we present the amounts of CH_4 and N_2O emissions per head of cattle, distinguishing between dairy and non-dairy cattle, for each EU country. In this way, we provide a brief overview of the farming systems within Europe and are able, in Section 4, to estimate by how much cattle numbers need to be reduced in each EU country to achieve (part of) the GHG targets. Section 5 examines how the downsizing of EU cattle herds could affect the livestock and meat trade as well as beef consumption. Section 6 concludes with a brief review of other options available for reducing greenhouse gas emissions from cattle.[5]

Box 1. **Glossary**

Cattle refers to domestic animals of the species *Bos Taurus*. Cattle and water buffalo *Bubalus bubalis* together are called **bovines**. National inventories of cattle then also include buffaloes.

Alongside distinctions related to age and sex, a further division is often made between dairy cattle and others.

Dairy cattle or **a dairy cow** refer(s) to a female bovine animal(s) that has already calved (including those less than 2 years old) and which, by reason of its breed or particular qualities, is kept exclusively or principally to produce milk for human consumption or for processing into dairy products (i.e. cream, butter, yoghurt or cheese).

Non-dairy cattle include all other types of bovines. Adult females include heifers (female bovines that have not yet calved) and non-dairy cows (sucklers). Adult males include in-growth bovines (bulls or uncastrated males; steers or castrated males). A **calf** means a bovine animal up to six months old.

The typical lifespan of each group varies. Veal calves are usually slaughtered within eight months, beef cattle within the first 2.5 years and dairy cows within 5 years.

Beef is the meat from the slaughter of animals aged 1 year or more. Certain breeds of cattle are reared specifically for their beef (e.g. Aberdeen Angus, Belgian Blue, Charolais) although beef can also come from dairy cattle (in the EU mainly Holstein-Friesian). Veal is the meat of bovine animals less than 1 year old (usually male calves and young cattle).

Source: mainly Eurostat.

5. It is important to remember that not all emissions associated with feed production, land use and land-use change, energy consumption, manure spreading, transport and feed processing are included in our analysis. Likewise, emissions associated with off-farm manure storage and processing are outside the scope of this document. Addressing all these aspects would require the use of life cycle assessment (LCA) methods. See, for example, Pishgar-Komleh and Beldman (2022) or FAO (2023) for recent reviews of LCA studies. Instead, we focus on the impact of a downsizing in EU cattle herds, which is increasingly being discussed.

2. GHG emissions in EU agriculture: Current levels and targets for 2030

The European Green Deal sets ambitious targets for reducing GHG emissions at the 2030 horizon. In particular, the package of proposals "Fit 55" implies a reduction of at least 55% in GHG emissions by 2030 (compared to 1990) for the EU as a whole in order to fight climate warming.

However, under the current arrangement, agriculture has specific targets for reducing GHG emissions. As a sector not subject to the EU Emissions Trading System (EU-ETS)[6], its targets consist in a 40% reduction of emissions by 2030 at the EU level (compared to 2005). Importantly, the Effort Sharing Regulation (ESR) specifies how efforts are to be shared between EU countries, based on their level of wealth (calculated using GDP per capita) and a cost-effectiveness analysis (the criteria for which are somewhat opaque). It should be noted that the EU Climate Law has made the targets set by the ESR legally binding.[7]

Table 3 presents targets for individual EU countries, as set in the ESR, and current levels of GHG emissions for agriculture in 2021 (i.e. the last data available). The ESR's effort ranges from 10% (in Bulgaria) to 50% (in Denmark, Germany, Luxembourg, Finland and Sweden). With the exception of Croatia, which has already reached its 2021 target, most countries still have a long way to go to reduce GHG emissions from agriculture. Even in countries where the ESR's effort was set quite low (Bulgaria, Latvia and Poland), GHG emissions will have to be reduced by much more to reach 2030 targets, as GHG emissions have increased (not decreased) from 2005 to 2021. More generally, the data for the last decade show no improvement in GHG emissions from agriculture, where emissions fell almost exclusively between 1990 and 2010 (Figure 2). Furthermore, based on projections by the European Environment Agency (EEA, 2023), if currently planned measures in each national EU agricultural sector are implemented, only a modest EU-level decline of 8% is expected by 2030 compared to 2005, far

6. Other sectors not subject to the EU-ETS are road transport, heating of buildings, small industrial installations and waste management. In 2027, the new EU-ETS will include road transport and buildings. Emissions in agriculture have two characteristics making their inclusion in the EU-ETS difficult: they are diffuse and they depend on a range of fairly complex pedoclimatic factors (Foucherot and Bellassen, 2013).

7. EU, 2021, Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ("European Climate Law"), OJ L 243, 9.7.2021, pp. 1-17.

from the target of 40%. This highlights the need for further action to reduce non-CO_2 emissions from agriculture.

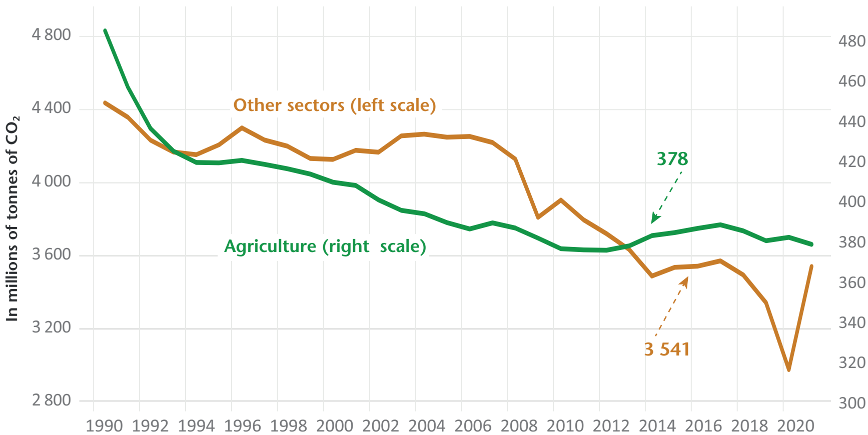
Table 3. **Current and targeted GHG emissions by 2030 in EU agriculture**

	GHG emissions in 2021	Evolution in GHG emissions since 2005 (reduction if -, otherwise increase)	Targeted reduction in GHG by 2030 (compared to 2005) if -, otherwise increase*		Targeted GHG emissions for 2030
	in millions of tonnes	in %	in %	in millions of tonnes	in millions of tonnes
EU 27	**378.4**	**-2.8%**	**-40.0%**	**-144.9**	**233.5**
Austria	7.2	0.6%	-48.0%	-3.5	3.7
Belgium	9.4	-4.7%	-47.0%	-4.2	5.2
Bulgaria	6.1	22.5%	-10.0%	-1.6	4.5
Croatia	2.7	-19.7%	-16.7%	0.1	2.8
Cyprus	0.6	4.6%	-32.0%	-0.2	0.4
Czechia	7.8	0.4%	-26.0%	-2.1	5.8
Denmark	12.1	-2.9%	-50.0%	-5.9	6.2
Estonia	1.6	30.7%	-24.0%	-0.7	0.9
Finland	6.3	-0.1%	-50.0%	-3.1	3.2
France	66.2	-9.7%	-47.5%	-27.7	38.5
Germany	56.3	-5.5%	-50.0%	-26.5	29.8
Greece	8.0	-13.8%	-22.7%	-0.8	7.2
Hungary	7.2	18.4%	-18.7%	-2.3	4.9
Ireland	23.0	12.0%	-42.0%	-11.1	11.9
Italy	32.7	-5.5%	-43.7%	-13.2	19.5
Latvia	2.3	25.8%	-17.0%	-0.8	1.5
Lithuania	4.3	4.8%	-21.0%	-1.1	3.3
Luxembourg	0.7	10.7%	-50.0%	-0.4	0.3
Malta	0.1	-4.1%	-19.0%	0.0	0.1
Netherlands	18.0	-1.5%	-48.0%	-8.5	9.5
Poland	34.0	7.5%	-17.7%	-8.0	26.1
Portugal	7.3	4.7%	-28.7%	-2.3	4.9
Romania	19.2	-9.2%	-12.7%	-0.7	18.4
Slovakia	2.4	-10.7%	-22.7%	-0.3	2.1
Slovenia	1.8	0.8%	-27.0%	-0.5	1.3
Spain	34.4	-4.3%	-37.7%	-12.0	22.4
Sweden	6.7	-3.7%	-50.0%	-3.2	3.5

Eurostat and European Commission; computations of the author.

* Such as defined in the Effort Sharing Regulation (ESR).

Figure 2. **Development in GHG emissions (agriculture versus other sectors)**



Eurostat; computations of the author.

3. The contribution of EU cattle to GHG emissions

The empirical literature aiming at measuring GHG emissions (of CH_4 and N_2O) from ruminants, and analysing the factors responsible, is quite abundant. In Box 3, we provide a brief review of the main factors at work and the mitigation options in the case of cattle. For an in-depth and up-to-date review, see, for example, Bačėninaitė *et al.* (2022) or Rivera and Chará (2021).

Based on field and laboratory experiments, the Intergovernmental Panel on Climate Change (IPCC) proposes guidelines to measure emissions per head of animal, accounting for some local characteristics (breed, feed, climate, etc.). These guidelines are used by the developed countries, which are required to report their emissions each year to the United Nations Framework Convention on Climate Change (UNFCCC). In a few words, reporting is based on national activity statistics multiplied by emission factors. While the main disadvantage of this method is its roughness compared to the empirical literature, the advantage is that it provides harmonised measures across countries. In what follows, we rely on data from the UNFCCC to overview and then compute the contribution of cattle to GHG emissions, distinguishing between dairy and non-dairy cattle.[8]

8. More precisely, we rely on Tables 3.As1, 3.As2, 3.B(a)s1, 3.B(b) of CRF Tables. Such data are used by Eurostat to evaluate GHG emissions in each EU country. For the choice of CO_2 equivalence factors, we follow Eurostat by setting the value of coefficients to 28 for CH_4 and 265 for N_2O.

As discussed in the introduction, livestock emit methane (CH_4) through enteric fermentation and, in addition to methane, they also emit nitrous oxide (NO_2) through manure management.

3.1. GHG emissions through enteric fermentation

Enteric fermentation is a natural part of the digestive process in ruminant animals such as cattle, sheep, goats and buffalo. Microbes in the digestive tract, or rumen, decompose and ferment food, producing methane as a by-product.

In a nutshell, from the empirical literature, emissions of methane from enteric fermentation are found to depend on various, and sometimes intricate, factors like age, weight, feed intake, diet (grazing or feed trough), activity (milk production or fattening), breed, etc. The consensus is that dairy cattle emit much more methane (2.5-3 times more) than non-dairy cattle. On average, one head of EU dairy cattle emits 132.8 kg of CH_4 per year while the corresponding figure is 47.9 kg for a head of non-dairy cattle (Table 4). The difference in CH_4 depends mainly on the much larger feed intake of dairy cattle in order to produce milk (Li *et al.*, 2018). Other factors such as differences in feed components are also at work, which aim to increase either the milk performance (quantity) or its fat and protein content (nutritional quality).

Large differences arise across countries with, in general, dairy cattle in northeastern EU countries emitting much more methane through enteric fermentation than those in oceanic or temperate climates,

Table 4. **Total direct GHG emissions per head of EU cattle**

In kg of gas/head/year, 2021	Enteric fermentation	Manure management		Total
	CH_4	CH_4	N_2O	Equiv. CO_2*
Dairy cattle	132.8	21.43	0.62	4 483
Non-dairy cattle	47.9	5.3	0.26	1 559
Ratio Dairy/Non-dairy	2.8	4.0	2.4	2.9
		In % of equiv. CO_2		
Dairy cattle	82.9%	13.4%	3.7%	100.0%
Non-dairy cattle	86.1%	9.5%	4.4%	100.0%

UNFCCC; computations of the author.

**Emissions of CH_4 and N_2O are expressed in CO_2-equivalent, taking into account a global warming potential of 28 et 265 for CH_4 and N_2O (values used by Eurostat).*

where grazing is more widespread (Figure 2A). However, this finding applies to a lesser extent to non-dairy cattle (Figure 3A). Several complex factors explain the differences across countries in terms of methane from enteric fermentation, including cattle breeds and production systems, and partly differences in climate.

3.2. **GHG emissions through manure management**

Manure management, which includes the activities of manure storage and treatment, before it is used as fertilizer or fuel, is another important source of GHG.[9] Emissions from this category are largely dependent on how manure is stored. In anaerobic conditions, liquid-stored management systems (i.e. lagoons, slurry) predominantly produce methane, while dry-based manure enhances mainly the production of nitrous oxide (FAO, 2023). Local management practices and climate, which differ greatly between regions and countries, will determine the importance of CH_4 and N_2O emissions. In particular, longer storage durations and higher temperatures cause higher CH_4 emissions. In the case of N_2O, emissions are positively related to the intake of feed with high nitrogen concentrations (i.e. certain amino acids), storage duration, temperature and increased aeration (Moeletsi and Tongwane, 2015).

As with enteric fermentation in dairy cattle, a certain distinction holds in terms of GHG emissions between countries in northeastern Europe and those with a more temperate climate (Figure 3A). This confirms the importance of housing systems, with cattle confined indoors emitting more GHG than cattle grazing in meadows. It should be noted that this finding holds in part because only direct emissions are measured here: when cattle graze, the manure is left in the meadows, so the question of management no longer arises. However, other factors are at work and, in particular, a diet radically different between intensive and extensive production systems.[10]

Malta looks like an outlier because of its dry-based manure, where low CH_4 emissions result in high N_2O emissions (see the green and

9. Eurostat data do not allow the breakdown of manure directly applied to fields by type of livestock. Therefore, only data on manure management are considered.

10. In addition to the housing system (indoor, outdoor or mixed), production systems for cattle differ in a variety of dimensions (Nguyen *et al.*, 2010), including the diet composition (more or less grazing, grass silage and concentrates). The age and weight of animals at slaughter (in search of profitability and in connection with the breed) are other important parameters for distinguishing production systems, in particular beef production systems.

orange bars in Figures 3 & 4). By contrast, in countries and regions where cattle are confined for part of the year, manure is commonly handled in liquid systems, which increases the potential for CH_4 production and reduces N_2O production.

3.3. **Total direct GHG emissions: A synthesis**

Once converted into CO_2 equivalent, emissions from manure management appear to account for 17.1% of total direct emissions in the case of dairy cattle and 13.9% in the case of non-dairy cattle, mainly through the additional emissions of methane (Table 4). In total, emissions of N_2O account for less than 5% of total direct emissions per cattle head.

Figure 3A. **Methane emissions from enteric fermentation and manure**

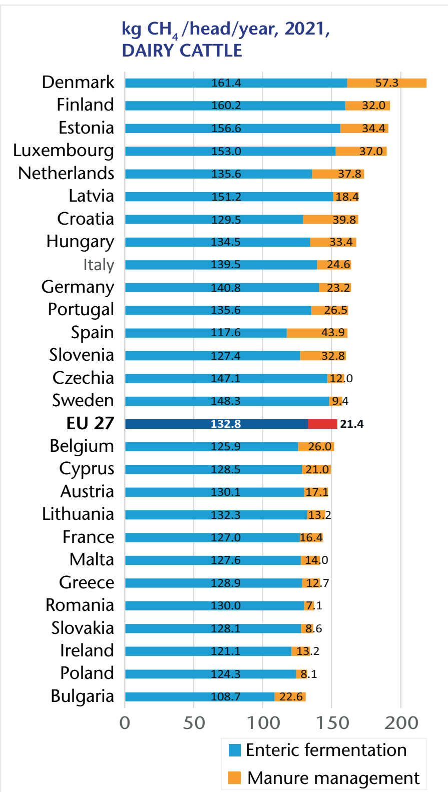
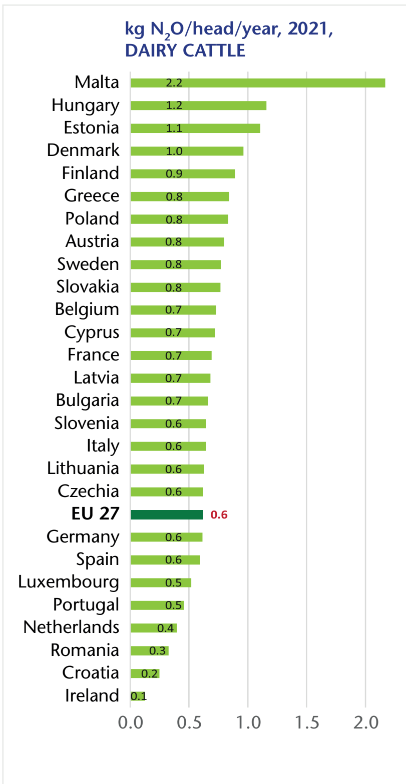


Figure 3B. **Nitrous oxide emissions from manure management**



UNFCCC(2023); computations of the author.

Figure 4A. **Methane emissions from enteric fermentation and manure**

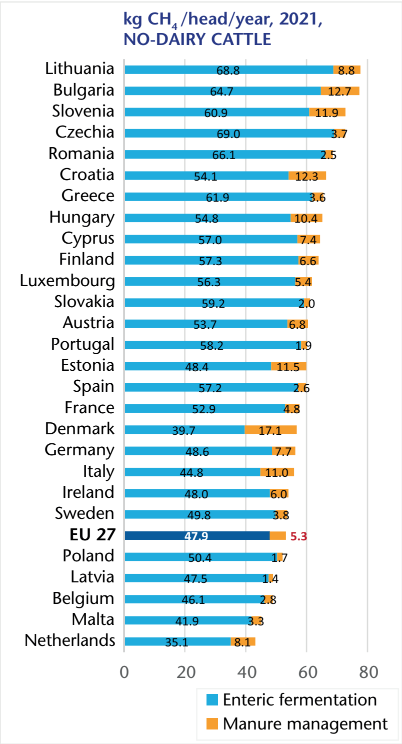
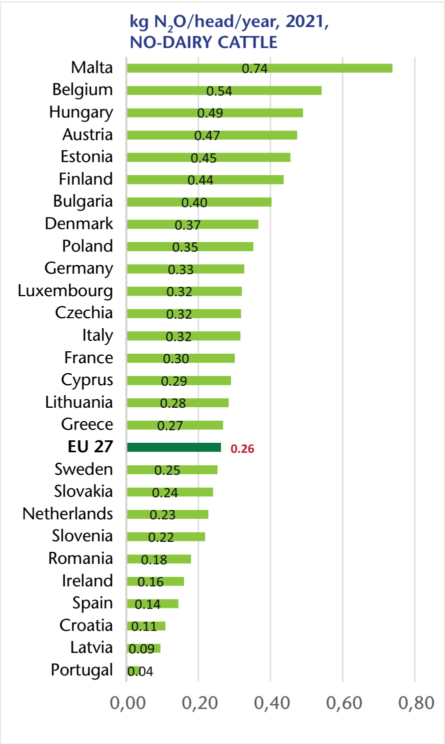


Figure 4B. **Nitrous oxide emissions from manure management**



UNFCCC(2023); computations of the author.

Regarding dairy cattle, the highest total direct emissions per head in CO_2 equivalent is for Denmark, with 6 379 kg/year, and the lowest for Ireland, with 3 794 kg/year (Appendix 2). As for non-dairy cattle, Bulgaria ranks the highest in terms of total direct emissions per head, with 2 273 kg/year, and the Netherlands the lowest, with 1 268 kg/year.

It should be noted that these figures for total direct emissions should not be interpreted as signs that the EU's cattle systems are efficient. First, emissions per head have to be related to the potential for meat and milk production. For example, once meat production is considered, the footprint of Denmark's dairy cattle falls considerably, to rank among the lowest within the EU, and, when considering milk produced, the footprint of its dairy cattle stands roughly at the EU average (Appendix 2.1). Second, and importantly for our purposes, a system with (semi-)confined cattle rather than with grazing cattle could be more suitable to the implementation of technological mitigation solutions (FAO, 2023; Cooper *et al.*, 2013), such as feed additives (to reduce methane emissions from enteric fermentation) or the capture of methane from manure management (to transform it into biogas). We will discuss this in the conclusion, after analysing the much more radical mitigation solution consisting of downsizing cattle numbers.

4. The reduction of EU cattle numbers to reduce GHG emissions in agriculture

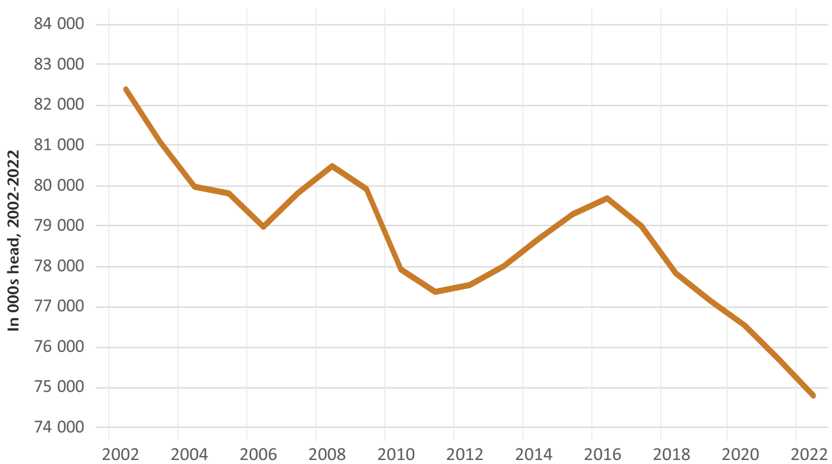
4.1. The current EU cattle stock in a nutshell

With 74.8 million head at the end of 2022, the EU has a sizeable livestock of bovine animals.

The majority of EU livestock is held in just a few EU countries: France (with 23% of EU livestock), Germany (15%), Poland, Spain and Ireland (9% each) and Italy (8%) together account for more than 70% of the total.

During the past two decades, livestock stocks have shrunk across the EU, with bovine numbers decreasing about 9% between 2002 and 2022 (Figure 5). This downward trend has been interrupted twice: in

Figure 5. **Developments of cattle livestock in the EU**



Eurostat; computations of the author.

2007/2008 following restrictions on imports from Brazil, and in 2012/2016 following the expected end of EU milk quotas by 2015. This latest episode triggered a major restructuring of the sector, with numerous small dairy farms abandoning milk production in favour of beef production, while medium-sized-to-large farms expanded their dairy cattle herds. This restructuring was particularly strong in Ireland, where dairy cows have increased by 42% over 2012-2022, and in Poland, where farmers have switched from dairy to non-dairy cattle, leading to a 17% increase in bovine animals over the same period.

The reduction in EU livestock comes against a backdrop of falling meat consumption, particularly beef (see below).

4.2. **Assumptions regarding the downsizing in EU cattle stocks**

We assume that, in each EU country, cattle must contribute 30% of the reduction in GHG emissions targeted by 2030 along the lines defined by the ESR (Table 3). For that purpose, we use data for cattle in 2022 (provided by Eurostat) and for emissions per head/per year (provided by UNFCC).[11] We consider that the reduction in cattle will take place within a fixed structure of production (the one existing in 2022), meaning that, in each country, the ratio of dairy to non-dairy cattle remains unchanged over the exercise. It should be noted that the 2030 targets are used only to set numerical targets for GHG reductions, as such targets may be potentially reached at any time outside 2030. Our exercise does not take into account either the dynamics in the downsizing or how to operationalize or finance it.

Of course, more sophisticated assumptions could have been made. In particular, it would be interesting to consider how the ratio of dairy to non-dairy cattle could be – or needs to be – shifted in the context of cattle downsizing. Indeed, dairy as opposed to non-dairy cattle are not only emitters of very different GHG levels (per head, per kg of milk or meat) but also providers of very different by-products (i.e. only meat for non-dairy cattle, both milk and meat for dairy cattle). Moreover, the eating quality of meat (i.e. tenderness, flavour, juiciness) as well as its nutritional quality (i.e. protein, fat) can differ between dairy and non-dairy cattle. Farvendin *et al.* (2022) provide an illuminating starting point in this respect, with some thoughts on how cattle should be

11. In this exercise, we also take into account buffalo, whose numbers in the EU have reached near 500 000 in 2022, and whose levels of CH_4 and N_2O emissions per head are different from other cattle (Appendix 1).

shifted in developed countries, where productivity gains in terms of milk and meat per head are no longer available and where GHG emissions need to be curbed. However, their work is silent regarding the eating quality of meat, focusing almost exclusively on the trade-off between feed efficiency and the sustainability of meat production. Whether the eating quality of meat from dairy cattle is inferior to that from non-dairy cattle remains a hot and still open question that we also need to address, especially in a context where downsizing in EU cattle stocks would come at the cost of reducing EU citizens' beef consumption. All these highly relevant issues deserve an additional whole article but are beyond the scope of this article.[12]

As a first step, we want to keep the exercise simulating the impact of a reduction in EU cattle numbers as simple as possible in order to paint the big picture of the situation.

With these caveats in mind, we aim at evaluating the downsizing of EU cattle stock associated with a reduction of 43.5 million tonnes in GHG emissions for the EU as a whole (i.e. 30% of 144.9 million tonnes of GHG in Table 3).

4.3. **The resulting downsizing in EU cattle stocks**

Let's consider the big picture. We find that, in 2022, 1 million EU cattle have emitted, on average, around 2.6 million GHG tonnes through enteric fermentation and manure management. This means, in first approximation, that EU cattle need to be downsized by 16.3 million head to reach 30% of the GHG 2030 targeted reductions. Put differently, EU cattle livestock would number 58.6 million head (Table 5). For the EU as a whole, that is equivalent to a 22% reduction in cattle compared to 2022, or 2.5 times the reduction in cattle observed over 2002-2022 (see Figure 5).

As reported in Table 5, the percentage of downsizing would be the greatest in Finland and Denmark (respectively -47% and -39%), as those countries combine both a high effort for reduction in GHG (as defined by the ESR) and a low achievement to date (Table 4). By contrast, the reduction in livestock would be lowest in Romania (-4%), as most of its GHG reduction targeted for 2030 has already been

12. See, for example, Bown *et al.* (2016) and Bureš and Bartoň (2018) for a contrasting view on the eating quality of meat, depending on the meat versus milk purpose of production. See also Kostusiak *et al.* (2023) for the nutritional quality of meat according to breeds in the case of Poland.

achieved. Croatia could potentially increase its livestock population, as its GHG reduction targeted for 2030 is already exceeded.

In head of animals, France would face the largest fall in numbers (-3.6 million), then Germany (-2.4 million), Spain (-1.6 million), Italy (-1.5 million) and Ireland (-1.2 million).

Table 5. **Downsizing in EU cattle stocks**

	Head of cattle (000s)		Downsizing in cattle (if -)		GHG reduction (if -)
	2022	If contribution of cattle to 30% of GHG reduction*	In 000 head	In %	In millions of CO_2 equivalent*
EU 27	**74 808**	**58 554**	**-16 254**	**-22%**	**-43.5**
Austria	1 861	1 418	-443	-24%	-1.0
Belgium	2 286	1 730	-556	-24%	-1.3
Bulgaria	580	384	-196	-34%	-0.5
Croatia	422	436	14	3%	0.0
Cyprus	81	60	-21	-26%	-0.1
Czechia	1 390	1 160	-231	-17%	-0.6
Denmark	1 466	893	-573	-39%	-1.8
Estonia	250	176	-74	-29%	-0.2
Finland	822	436	-386	-47%	-0.9
France	16 986	13 334	-3 652	-21%	-8.3
Germany	10 997	8 593	-2 404	-22%	-8.0
Greece	582	447	-135	-23%	-0.2
Hungary	894	663	-231	-26%	-0.7
Ireland	6 552	5 314	-1 238	-19%	-3.3
Italy	6 049	4 543	-1 506	-25%	-4.0
Latvia	391	306	-85	-22%	-0.2
Lithuania	642	520	-121	-19%	-0.3
Luxembourg	186	146	-40	-22%	-0.1
Malta	14	13	-1	-9%	0.0
Netherlands	3 751	2 825	-926	-25%	-2.5
Poland	6 448	5 532	-916	-14%	-2.4
Portugal	1 579	1 210	-369	-23%	-0.7
Romania	1 834	1 768	-65	-4%	-0.2
Slovakia	433	398	-35	-8%	-0.1
Slovenia	465	401	-64	-14%	-0.2
Spain	6 455	4 812	-1 643	-25%	-3.6
Sweden	1 391	1 034	-357	-26%	-1.0

Eurostat; computations of the author.

* The targets of GHG reductions are those defined in the Effort Sharing Regulation (see Table 4). The choice of a 30% contribution through cattle downsizing is the author's.

5. The impact of a downsizing EU cattle stocks on trade and bovine meat consumption

A downsizing in EU cattle livestock will necessarily involve adjustments in the related flow variables, i.e. calving, slaughters, consumption of meat and dairy products, etc. In a closed economy, the downsizing in cattle livestock would affect in an exact proportional way its flow variables, *ceteris paribus*. In an open economy, things turn out to be different because trade, both within and outside the EU, can compensate for the lower "local" (EU) availability of cattle products.[13]

The impact of a downsizing in EU cattle on trade, and therefore on consumption patterns, is likely to depend on a range of factors, making a precise evaluation impossible. Here are some key elements for brainstorming, some of which will be developed in the following sections:

- Both the level and direction of trade flows will change, as EU countries are important exporters of bovine meat, especially within the EU.
- In general, people in EU countries have a strong appetite for bovine meat, and some EU countries currently rely on significant (net) imports to satisfy their consumption. Conversely, some EU countries are major (net) exporters. Whether the latter will meet local demand first or continue to export much of their production is an open question.
- The EU demand for bovine products itself may be shifted downwards by the downsizing of EU cattle stocks, as it may raise further awareness about the detrimental impact on the environment and health of a diet that relies on bovine meat.
- At the same time, some beef-loving EU citizens could leave their demand for beef unchanged, putting pressure on beef prices and fuelling production abroad.
- The latter scenario would create a schizophrenic situation in which the EU would become a net importer from abroad, leading to loss of market share for EU countries, with no sizeable effects on the reduction in global GHG emissions. Worse still, GHG emissions may increase at the global level, since livestock would be now produced abroad, and additional emissions would arise from imports with extra-EU partners.

13. In what follows, we concentrate our analysis on bovine meat, as dairy products (milk, but also butter, yoghurt and cheese) involve issues other than meat. Moreover, we use the term "beef" to refer to all bovine meat, including veal (see Box 1).

- In such a schizophrenic context, it is rather difficult to imagine that EU trade policy would remain unchanged and that some kind of taxes (e.g. customs duties at the EU borders or, at least, "mirror clauses") would not be applied to extra-EU countries.

5.1. **The current EU trade and beef consumption in "cattle head equivalent": An evaluation**

International trade in cattle mainly takes the form of meat, for reasons of convenience and animal welfare. Only a few EU countries, mainly with a common border, are involved in the trade of live animals, either for fattening young bovines (e.g. France exporting calves to Italy) or for slaughtering mature ones (e.g. the Netherlands exporting to Poland). Extra-EU trade in live bovines may occur where boat journeys of less than 48 hours are possible (e.g. Spain exporting to the Middle East).

Determining how many head of cattle are involved in the trade of bovine meat is, by definition, very challenging. We have to infer the number from different databases, each relying on different units, which requires the use of conversion factors to transform kilograms of products or carcasses into head of cattle. Our estimates must therefore be taken with caution. Even for trade in live animals, the use of conversion factors is necessary, as Eurostat no longer provides data per head but only in kilograms or in euros. Box 2 describes the problem and the conversion factors used to solve it. In this paper, our experiments are based on a strategy that relies on "carcass weight equivalent" (CWE) as a departure point.

Box 2. **Different units for measuring livestock and its products**

At farm level, livestock is generally measured per "head" or "number". Eurostat provides a livestock inventory for each EU country, broken down by type (cows, bulls, buffaloes, etc.) and several age groups. The UNFCCC tables provide additional information on the average weight of live animals for two to six categories of cattle, depending on the country. In the EU, dairy cattle and non-dairy cattle had average weights of 616 kg and 398 kg respectively in 2022. It should be noted that the weights of livestock inventory may differ from the weights of cattle to be (internationally) traded and slaughtered.

In the meat industry, the "carcass weight" is the unit of reference. The "dressing rate" is a measure of the weight remaining after slaughter (i.e. the animal killed minus its skin, head, feet and intestines) as a percentage of the live weight. According to the empirical literature, the dressing rate is generally estimated at between 50% and 60%, depending on the type of cattle, its breed, gender, diet, age and weight at slaughter, etc. Before reaching the store, the carcass is further processed into the retail cuts to obtain the meat on the one hand, and the edible offal on the other. Fat is another by-product of the cutting process. Empirical literature suggests that the additional weight loss (unnecessary bones, fat, etc.) is typically in the region of 25-30%, meaning that the "carcass cutting yield" (or the percentage of carcass weight remaining as "take home" product) is 70-75%.

Eurostat(Comext) provides data on livestock, meat and other products, both expressed in tonnes of "carcass weight equivalent" (CWE), for intra-EU and extra-EU trade. In addition, for each EU country and its intra-EU and extra-EU partners, Eurostat provides data on cattle, meat and other products, expressed in kg or in euros (or national currencies). Last, Eurostat gives data on slaughters expressed in heads and in tonnes of CWE for each EU country, thus allowing computing the average weight of a carcass. In the EU, the latter stood in average at 293 kg in 2022.

In addition, for 189 countries worldwide, the FAO provides data on production, trade and consumption in tonnes of CWE for beef meat (excluding livestock and other products).

Moving from one type of unit to another to get insights into the impact of downsizing cattle stocks on trade and consumption requires a certain amount of caution. In this document, taking stock of the previous explanations, we have set the conversion factors at 50% for the dressing rate, 70% for the carcass cutting yield and 300 kg for the carcass weight to be traded. The corresponding weights are then as follows:

Live weight	→	Carcass weight	→	Retail weight
600 kg		300 kg		210 kg

Sources: Piedrafita *et al.* (2003), Sakowski *et al.* (2022), Bown and Thomson (2016); elaboration of the author.

Beef meat in "cattle head equivalent"

The methodology used to measure how many head are involved in the international trade and consumption of beef meat is as follows. Production, consumption, exports and imports of meat (in 1000 t, CWE) are taken from FAOSTAT for each EU country, then converted assuming a carcass weight of 300 kg per head. In addition, data on exports and imports (in 1000 t, CWE) provided by Eurostat(Comext) are used to disentangle intra-EU from extra-EU trade. Annual averages over 2017-2021 are calculated to remove trade disruptions due to the

Covid period and Brexit. It should be noted that the United Kingdom is treated statistically as a non-EU country over the whole period. The results are presented in Table 6.

Based on our methodology, "production" can be interpreted as the slaughter of cattle to produce meat. Under our assumption, we found that 23.3 million cattle have been killed annually over the period 2017-2021 within the EU. Data taken directly from Eurostat give 23.4 million cattle slaughtered over the same period, which confirms the relevance of our methodology.

In terms of consumption, EU citizens have been eating, on average, 21.1 million cattle each year, which means that the EU is a net exporter of around 1.8 million cattle (3.063 million of EU exports – 1.312 million of EU imports).

Another important finding is that there are huge intra-EU trade flows in beef meat, averaging the equivalent of 8.4 million cattle per year. Every EU country is involved in sizeable intra-EU trade, either on the import or export side, and often both. In average, over 2017-2021, 36% of the EU slaughters have been for intra-EU trade purposes. Even countries whose exports and imports are almost in balance (such as France or, to a lesser extent, Slovenia or Germany) have significant flows with other EU countries. For example, in the case of France, exports (respectively, imports) accounted for 18% (resp. 23%) of its production over 2017-2021. Each year, a little more than 1.9 million head of cattle (0.851 + 1.086) were traded by France and its partners, both within and outside the EU, but mainly within the EU, whereas in strictly quantity terms, 0.235 million (1.086 – 0.851) would have been "enough" to satisfy consumption, assuming that meat imports and exports are perfect substitutes. In reality, the assumption of perfect substitution does not hold: the quality of meat varies according to feed, breed and type of cuts, among other things (Sakowski *et al.*, 2022). Meat is market-segmented with, for example, in the case of France, most of the meat destined for the catering industry to be imported (Cour des Comptes, 2023). More generally, market segmentation for meat holds in all countries, with income purchasing power the main driver of demand for quality. Within the EU, the possibility of exploiting even minor differences in production costs, due to free movement of goods, is another factor explaining intra-EU flows of meat.[14]

14. See Jacques Le Cacheux (2023), in this review, for a similar statement.

Table 6. **Production, consumption and trade of bovine meat in animal head equivalent***

	Production	Consumption	Exports	Imports	Exports	Imports	Net imports
	In 000 head of bovines				In % of production		In % of consumption
Austria	749	460	418	198	55.8%	26.4%	-47.8%
Belgium	883	503	632	335	71.5%	38.0%	-59.0%
Bulgaria	57	84	5	43	9.3%	74.4%	44.4%
Croatia	145	175	47	95	32.1%	65.1%	27.4%
Cyprus	18	30	1	15	3.7%	85.2%	48.9%
Czechia	271	369	82	211	30.2%	77.6%	34.9%
Denmark	416	465	335	424	80.4%	101.9%	19.2%
Estonia	36	37	14	26	38.9%	72.2%	32.1%
Finland	289	343	19	81	6.5%	27.9%	18.1%
France	4 771	5 007	851	1 086	17.8%	22.8%	4.7%
Germany	3 693	4 049	1 205	1 607	32.6%	43.5%	9.9%
Greece	127	527	5	437	4.2%	344.7%	81.8%
Hungary	109	189	56	141	51.5%	129.4%	44.9%
Ireland	2 059	335	1 882	153	91.4%	7.4%	-515.5%
Italy	2 591	3 309	713	1 440	27.5%	55.6%	22.0%
Latvia	56	36	45	25	79.8%	44.0%	-55.6%
Lithuania	145	51	116	28	80.2%	19.4%	-171.4%
Luxembourg	34	59	13	37	37.3%	109.8%	41.6%
Malta	3	32	0	31	0.0%	920.0%	95.8%
Netherlands	1 458	925	2 038	1 565	139.8%	107.4%	-51.1%
Poland	1 902	133	1 972	119	103.7%	6.3%	-1389.5%
Portugal	319	718	59	475	18.4%	149.0%	57.9%
Romania	303	325	43	89	14.3%	29.5%	14.2%
Slovakia	37	112	11	96	30.9%	261.8%	75.6%
Slovenia	121	104	57	48	47.3%	39.6%	-9.0%
Spain	2 269	1 987	743	521	32.8%	22.9%	-11.2%
Sweden	460	759	35	363	7.7%	78.8%	43.1%
EU 27	**23 321**	**21 125**	**11 397**	**9 687**	**48.9%**	**41.5%**	-8.1%
Extra-EU trade			**3 063**	**1 312**	**13.1%**	**5.6%**	
Trade intra-EU			**8 334** ~	**8 375**	**35.8%** ~	**35.9%**	

FAOSTAT; Eurostat(Comext) for extra-EU and intra-EU trade; computation of the author.

* Method: Production, consumption, exports and imports of meat consumption (in 1000 t, CWE) are taken from FAOSTAT for each EU country, then converted assuming a carcass weight of 300 kg. Data on exports and imports (in 1000 t, CWE) provided by Eurostat(Comext) are used to disentangle between intra-EU from extra-EU trade. Annual averages over 2017-2021.

Determining the relative importance of "market segmentation" versus "production costs" factors in explaining these flows is beyond the scope of this paper. However, the emergence on the EU meat market of Poland, and to a lesser extent of Latvia and Lithuania, shows that lower production costs in these countries play a role. The footprint of such intra-EU beef flows is something we should be aware of, especially as these flows are on the rise, having almost doubled (as a share of EU consumption) since the early 2000s.

Extra-EU trade is comparatively smaller, accounting for 27% of total EU exports of meat and 16% of total EU imports over 2017-2021. However, the equivalent of 3 million bovine head was still exported each year in the form of meat (Table 6). In net export terms, the corresponding figure falls to 1.8 million.

International trade in live animals

Using CWE data from Comext(Eurostat), intra-EU trade of live animals can be rounded to 2.1 million head on average over 2017-2021, with half of it between France and Italy alone. Extra-EU exports are three times lower than intra-EU trade, with 0.80 million head exported, mainly towards Mediterranean and Middle Eastern countries. Extra-EU imports of live animals are even less, with a little over 7 000 head (Table 7).

Table 7. **EU trade in animal head equivalent***

In 000 head	Exports		Imports
Trade in meat			
EU 27	**11 397**		**9 687**
Extra-EU trade	3 063		1 312
Trade intra-EU	8 334	~	8 375
Trade in live animals			
EU 27	**2 913**		**2 054**
Extra-EU trade	789		7
Trade intra-EU	2 124	~	2 047
Total			
EU 27	**14 309**		**11 741**
Extra-EU trade	3 852		1 319
Trade intra-EU	10 458	~	10 422

Eurostat(Comext); computations of the author.

* Based on CWE, assuming a carcass weight of 300 kg. Average over 2017-2021.

It should be noted that these estimates, based on Comext(Eurostat) data, probably represent the lower range of EU trade in livestock, a point made by some animal welfare groups and acknowledged by the European Commission itself (Eurogroup for Animals, 2019; ECA, 2023). The main reason for this is that EU legislation does not require EU countries to collect and report data on the transport of live animals. Only national recording via TRACES is required to prevent transmissible diseases, but these national databases are appropriate for neither extracting nor analysing data on animal transport.

Total international trade: A summary

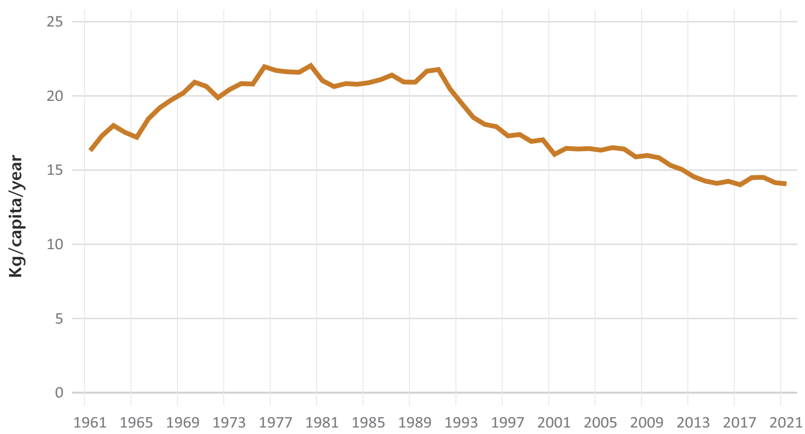
In total, rounding off the figures reported in Table 7, the EU countries have exported (respectively, imported) each year the equivalent of 14.3 million head (resp., 11.7 million) over 2017-2021. The bulk of trade is intra-EU, with 73% of exports and 89% of imports. Net extra-EU exports are equivalent to 2.5 million per year, which is still quite sizeable. However, the EU is rather a medium player on the worldwide bovine market, accounting for just 8% of total exports worldwide (net from intra-EU trade) over 2017-2021. Consequently, extra-EU partners should be reasonably expected to easily manage to import from other providers (i.e. Brazil, Australia) if EU countries were to cease extra-EU exports.

5.2. **Trend in consumption of beef meat: The past and some thoughts for the future**

Beef consumption in the EU has been falling for 30 years, and even 40 years if we consider the flat trend between 1980 and 1990 (Figure 6A). Mad cow disease, which appeared on a large scale in European herds in the early 1990s, led to a sharp drop in beef consumption, which has never recovered. In total, EU consumption of bovine meat has fallen from 22 kg/per head/per year in 1990 to 14 kg in 2021 or, put differently, by 36%. Growing concerns about health, the environment and animal welfare, as well as issues related to purchasing power, have led to this reduction in beef consumption. More and more people are becoming flexitarian, meaning they consume meat in a more parsimonious way and tend to favour a more plant-based diet, at least in the rich, developed countries.

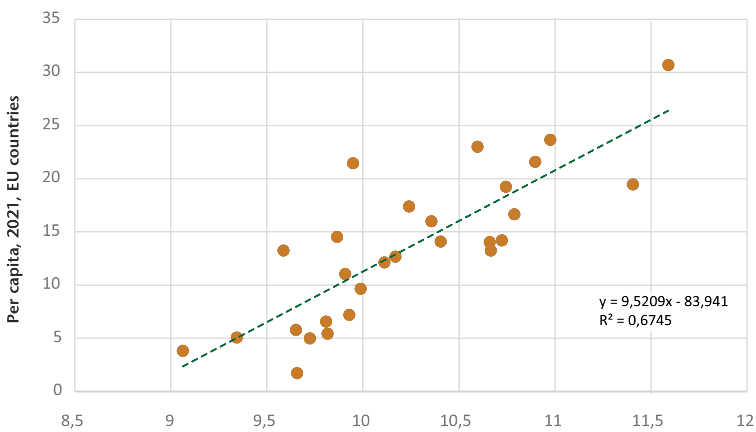
It should be noted that the EU average masks large differences in terms of beef consumption across countries. In particular, people in the Central and Eastern European and Baltic countries generally consume small amounts of beef, while people in the Western European and Nordic countries have a much more beef-based diet. In 2021, nine EU countries reported levels of beef consumption below 10 kg/per capita/per year, with Poland reporting the lowest level at only 1.7 kg/per capita/per year. At the other extreme, seven countries reported levels of beef consumption over 18 kg/per capita/per year, with Luxembourg recording 30.7 kg/per capita/per year in 2021.

Figure 6A. **Beef meat consumption in the EU 27**



FAOSTAT.
*CWE: carcass weight equivalent (see Box 2).

Figure 6B. **GDP and beef meat consumption**



FAOSTAT.
*X-axis: GDP per capita in US$, 2015 prices, in log.

These large differences in beef consumption across EU countries have something to do with cultural factors, but above all, with living standards. This latter point is illustrated in Figure 6A through the positive relationship between beef consumption and GDP (both per capita) for the 27 EU countries. The extent to which climate related-concerns will slow the catching up of countries lagging behind in terms of beef consumption remains an open question.[15] This will have some consequences on trade and consumption patterns, particularly in a context where EU cattle ranks are reduced.

5.3. **An attempt at a synthesis on the impact of a downsizing in EU cattle on trade and consumption patterns**

There is a great deal of uncertainty about the impact of a downsizing in cattle on beef meat consumption and trade, both of which are linked in complex ways to supply and demand factors, and to forces at work inside and outside the EU. Here are a few key conclusions and thoughts:

- In terms of equilibrium, assuming as a first approximation that a 22% downsizing in EU cattle numbers will lead to a 22% reduction in EU slaughters, the annual production of bovine meat would be lower by the equivalent of 5.2 million head of cattle.
- The remaining adjustments would be closely linked to the extent to which the main EU net exporters, namely Poland, Ireland and the Netherlands, would behave in a context where the supply of meat within the EU would be depressed. Indeed, the potential for adjustments appears highest in these three countries, and, Poland, Ireland and the Netherlands would be key players in the way trade would be redirected and reduced. For example, if they were to serve their populations first in order to keep their beef meat consumption constant, the cumulated drop in net exports would be the equivalent of 1.05 million head, which is not negligible.[16] The United Kingdom would be the partner most

15. To date, most studies or surveys aimed at documenting and forecasting meat consumption have focused on behaviours in Western, richer countries, with very few on Central and Eastern Europe or the Baltic States (see, for example, ProVeg International, 2020). The only trend we are sure of, in richer countries, is a shift towards a diet with less meat, especially among younger households, a trend that has been exacerbated by the Covid crisis. According to a note by the New Zealand Embassy (2020), Poland follows this trend, but not the Baltic States.

16. The net exports of Ireland would fall by 0.40 million. The corresponding figures would be 0.35 million for Poland and 0.30 for the Netherlands. The net exports of the three countries would drop by 26%.

threatened by a reduction in Ireland's net exports (given that half of its exports go to the UK). The fall in net exports from Poland and the Netherlands would have a greater impact within the EU, but in a very complex way due to the intertwining of intra-EU flows.

- It seems reasonable to assume that the impact of such restricted trade flows would fall disproportionately on countries in which net imports account for a large share of consumption. In the EU, 16 out of 27 countries have a share of net imports in consumption higher than 10%, and 9 countries a share higher than 40% (Table 6).
- All in all, the worst-case scenario, from the point of view of a beef-lover, is a situation in which he or she lives in a country that is heavily dependent on meat imports and facing a major downsizing in cattle numbers.
- In France, where the imports of beef meat are almost in balance with exports, we can assume, as a first approximation, that reducing cattle numbers would lead to a reduction in meat consumption of a similar proportion, i.e. around 21% (Table 5). By contrast, Italy would face a more pronounced adjustment, due to a 25% decrease in domestic cattle ranks combined with a reduction in imports from the three major EU exporters (Poland, Ireland, and especially the Netherlands). In addition, Italy could face a potential drop in livestock imports from France, amounting to 1 million young bovines (*broutards*).
- The complexity of intra-EU trade flows together with the considerable uncertainty regarding supply and demand behaviour undoubtedly preclude any precise and definitive measurement of how the adjustment in consumption would be distributed across EU countries following a reduction in EU cattle numbers. However, considering the EU as a closed economy, beef consumption within the EU would fall in line with the reduction in EU cattle, i.e. by 22%. This would put meat consumption in the EU at 11kg/per capita/per year. Based on a "carcass cutting yield" of 70% (Box 2), an EU citizen would eat an average ration of 150 g of beef once a week.

6. Conclusion

In this paper, we assess the impact of a downsizing of the EU cattle industry in order to achieve a 30% reduction in GHG emissions from agriculture (compared to 2005 levels). It should be noted that this 30% contribution of cattle to GHG reduction targets is not so impressive compared to the 49% contribution of cattle to direct GHG emissions from EU agriculture. Certainly, the corresponding 22% decrease in EU cattle numbers is impressive in light of the attachment of many citizens (and first and foremost farmers) to cows and bulls. We should acknowledge some cultural values associated with cattle grazing on meadows, even if, in some EU regions and countries, this looks like an Epinal print. We should add culinary values related to meat, cheese and milk (Peyraud and MacLeod, 2020). As argued by Pishgar-Komleh and Beldman (2022), EU beef production is important for socio-economic reasons and for the livelihood of European rural communities. In addition, ruminants have the unique ability to convert cellulose into milk and meat. They can thus exploit grasslands, some of which cannot be cultivated, and thus are not in direct competition with food (Faverdin *et al.*, 2022; FAO, 2023; Beauchemin *et al.*, 2020).

Consequently, reducing EU cattle numbers – by 22%, as in our experiment – might seem like a radical way to tackle the problem of GHG from EU agriculture. Government proposals to reduce cattle numbers in Ireland and the Netherlands have been widely opposed by farmers, who believe that this will lead to a huge loss of income and that it constitutes a U-turn in agricultural policy, as the end of milk quotas had encouraged them to expand their herds. French farmers were equally furious, arguing that the Court of Auditors' recommendations for downsizing would result in more imports of beef meat.

Certainly, there are less radical solutions to reduce GHG emissions than downsizing, particularly technological ones. For example, to the extent that the mix of feed can influence the amount of enteric fermentation per animal, or that a more balanced diet can meet animal protein needs, thus influencing manure composition, there is scope for reducing GHG emissions at the farm level (see Box 3). However, such solutions are either in their infancy or need to be scaled up in order to really reverse the current trend in cattle GHG emissions.

When taking stock of technological solutions, intensive farming systems appear to offer the greatest potential for reducing GHG emissions from cattle, either measured per animal or per unit of output (meat or milk).[17] To the extent that most of these technological solutions rely on precision farming, they are easier and more effective to implement in confined (or semi-confined) systems than in grazing systems (Beauchemin *et al.*, 2020). Given the difficulties in renewing farming generations, the further intensification of farming systems, but based on principles of sustainability, may be viewed as an alternative to achieve a sufficient level of beef production in the medium term while simultaneously mitigating GHG emissions. "Sustainable intensification", as defined by Clay, Garnett and Mortimer (2020), refers to a farming system that retains a productivist mindset but makes great use of technological advances to deal with environmental problems such as GHG emissions and water pollution.[18] However, the risk of worsening animal welfare – which appears to be more common in intensive than in extensive systems[19] – should not be underestimated and should be also addressed.

More generally, further scientific research and policy action should focus on a better articulation between cattle production (more generally, agricultural production) and GHG emissions. Certainly, this requires more R&D, more training for (young) farmers and a rethinking of the European Common Agricultural Policy (CAP) to give farmers the right (financial) incentives to invest in good practices for fighting climate warming. Internationally, the EU would be well advised to encourage its Global Methane Pledge partners, who are still too focused on fossil energy mitigation, also to reduce methane emissions from their cattle. Finally, at the European level, European authorities should question and debate the relevance of current intra-EU meat trade flows of such intensity, especially in terms of the carbon footprint of transport. Surely, this would call into question the very foundations of the Single Market, the rules of which were laid down in other areas when climate warming was not yet an issue. But this question should now be on the agenda of EU countries committed to a greener and more sustainable economy.

17. For example, a high milk yield per cow is typically accomplished by offering cows nutritionally precise diets, which is possible only in confined environments (O'Brien *et al.*, 2014). Petersen *et al.* (2013) state that, in the case of manure management, confined animal feeding operations appear to have the greatest potential for GHG mitigation.

18. See also Guyomard *et al.* (2023), in this review, for a discussion on future farming systems.

19. See Clay, Garnett and Mortimer (2020) on this point.

Box 3. Abatement options and the cost of livestock emissions

Measurements of GHG, and the promotion of abatement options, are not easy tasks due to the complexity of the biological processes involved in agricultural GHG emissions.

Abatement options for CH_4 and of N_2O emissions from cattle fall into two categories: technological options and farm-management options (Cooper *et al.*, 2013). Currently, among technological options available to reduce livestock emissions, some technologies may offer low-cost mitigation under certain conditions, but various other technologies either are in their infancy or their potential to induce large reductions in GHG emissions is still uncertain.

Technological options for mitigating livestock emissions

As methane production is affected by the composition of ruminant diets, decreasing the relative proportion of fibres to starches or carbohydrates consumed by animals would reduce CH_4 emissions. Feed additives and seaweed extracts can achieve this (Yan, 2022; Bačėninaitė *et al.*, 2022). However, there are practical impediments to such a change in livestock feed regimes, especially in extensive grazing systems. Other options include manipulation of the rumen microbial ecosystem and the use of anti-methanogenic vaccines, the latter being applicable to a wide range of production systems and complementary to other mitigation strategies.

Strategies for dealing with emissions that arise from manure management include using the capture of CH_4 for energy production. This can be achieved in intensive livestock operations where animals are housed or their movement is closely managed, but this is less useful in extensive grazing systems or in open dairy production. To date, capturing biogas is economically viable either for large farms or cooperative facilities, while for small operators, the offset value alone is unlikely to warrant the large capital cost of infrastructure.

Animal interventions could include breeding techniques that foster the development of livestock with improved production efficiency in terms of both N_2O and CH_4 per unit of product. Nitrification inhibitors, such as dicyandiamide, have been shown effective in reducing N_2O emissions from pasture under particular conditions, but their ability to deliver large-scale reductions across a wide range of climate and soil conditions remains uncertain (Cooper *et al.*, 2013).

Farm-management options for mitigating livestock emissions

A reduction in the age at first calving to 24 months and improvements in fertility are other factors that could allow for a significant reduction in GHG emissions (Yan, 2022).

Aeration of solid and liquid manure can substantially decrease CH_4 and N_2O emissions, with a variety of approaches available for different farming systems, at a low cost.

A combination of technological and farm-management options

Overall, most of the solutions based on rumen methanogenesis – the main source of CH_4 emissions – would individually have a moderate potential to curb GHG, less than 20% (Beauchemin *et al.*, 2020).It will therefore be necessary to combine strategies to attain a sizeable reduction in CH_4, but further research is required to determine whether combining anti-methanogenic solutions will have consistent additive effects. In addition, it is not yet clear whether a reduction in CH_4 emissions per animal would lead to an improvement in animal performance, i.e. a reduction in CH_4 emissions per unit of product (meat or milk), which is another important criterion for assessing the effectiveness of any mitigation strategy.

Sources: various references; elaboration of the author.

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APPENDIX

A1. Data related to buffaloes

Table A1-1. **EU livestock in buffaloes**

	Head	Share in EU total
Bulgaria	20 320	4.2%
Germany	11 680	2.4%
Greece	4 600	1.0%
Spain	980	0.2%
Italy	416 000	86.6%
Hungary	8 700	1.8%
Romania	17 900	3.7%
Total	**480 180**	**100.0%**

Eurostat; computations of the author.

Table A2-2. **Emissions of methane and nitrous oxide per dairy buffalo**

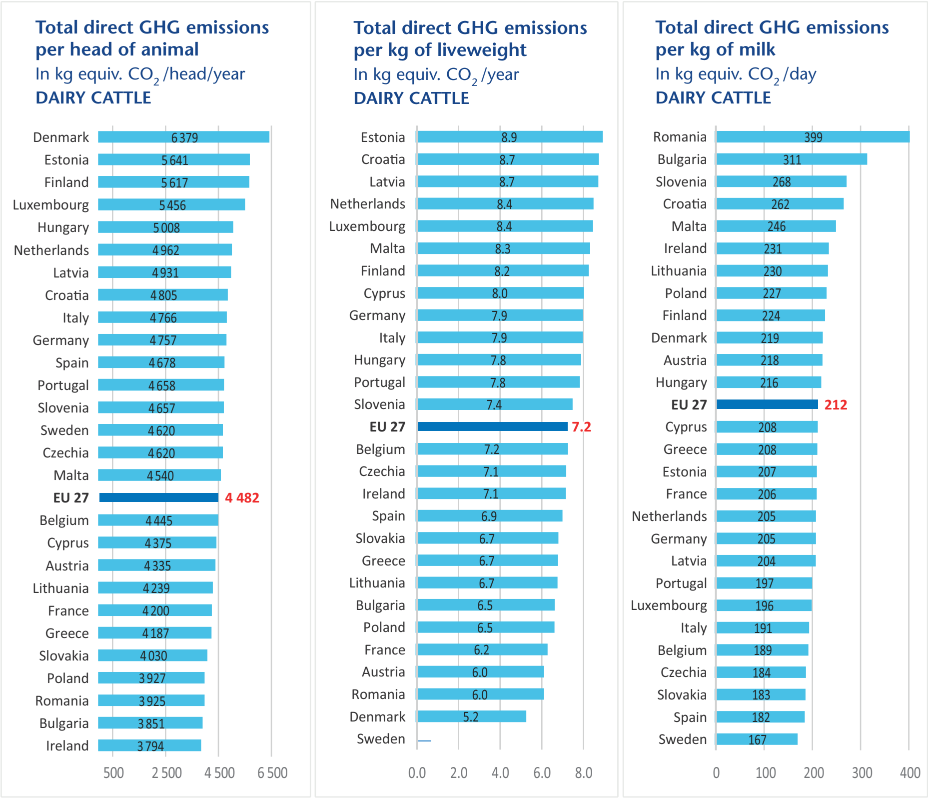
	Enteric fermentation	Manure management	
	CH4/kg/head	CH4/kg/head	N2O/kg/head
Bulgaria	65.67	5.00	0.12
Germany*	76.64	15.85	0.45
Greece	55.00	9.00	0.22
Spain*	76.64	15.85	0.45
Italy	76.64	15.85	0.45
Hungary	55.00	1.53	0.39
Romania	55.00	5.00	0.17

UNFCCC, 2023; computations of the author.

*Countries relying on Italian figures for emissions per head.

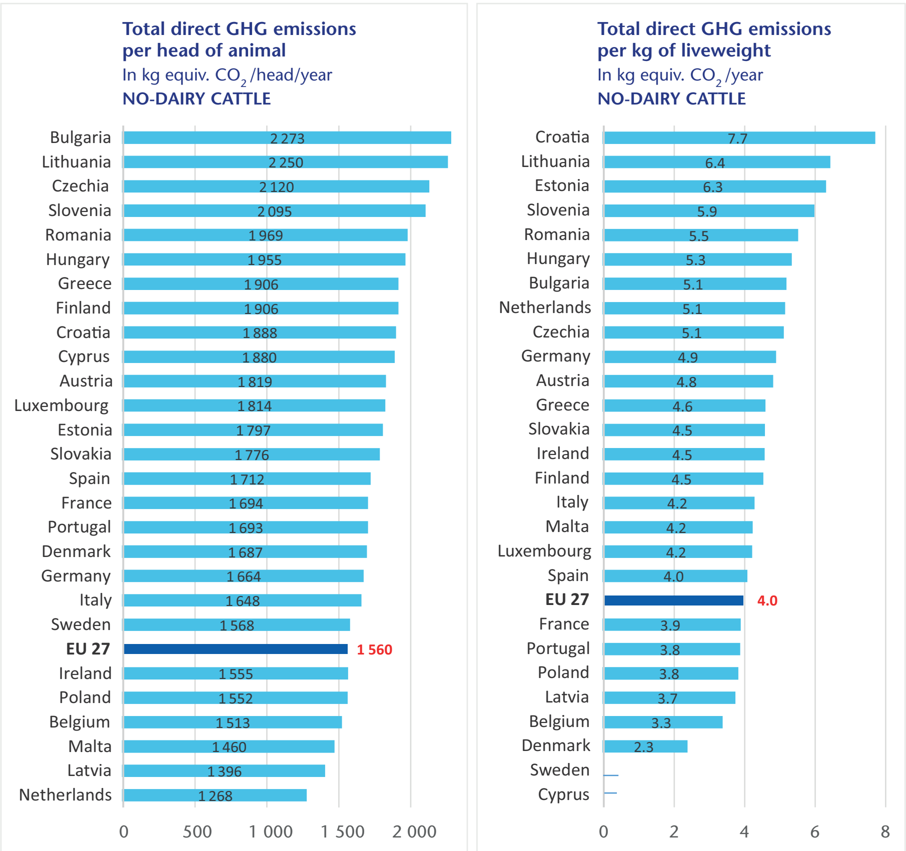
A2. Appendix related to total direct emissions (in CO_2 equivalent)

Figure A2-1. DAIRY CATTLE



UNFCCC (2023); computations of the author.

Figure A2-2. **NO-DAIRY CATTLE**



UNFCCC (2023); computations of the author.