UNIVERSITÀ DEGLI STUDI DI MILANO
DIPARTIMENTO DI SCIENZE AGRARIE E AMBIENTALI - PRODUZIONE, TERRITORIO, AGROENERGIA

June 17th, 2020

AAB PhD Course

Sustainability in animal production

# Environmental impact of animal production

Anna Sandrucci

# The challenges of sustainability in agriculture and livestock production

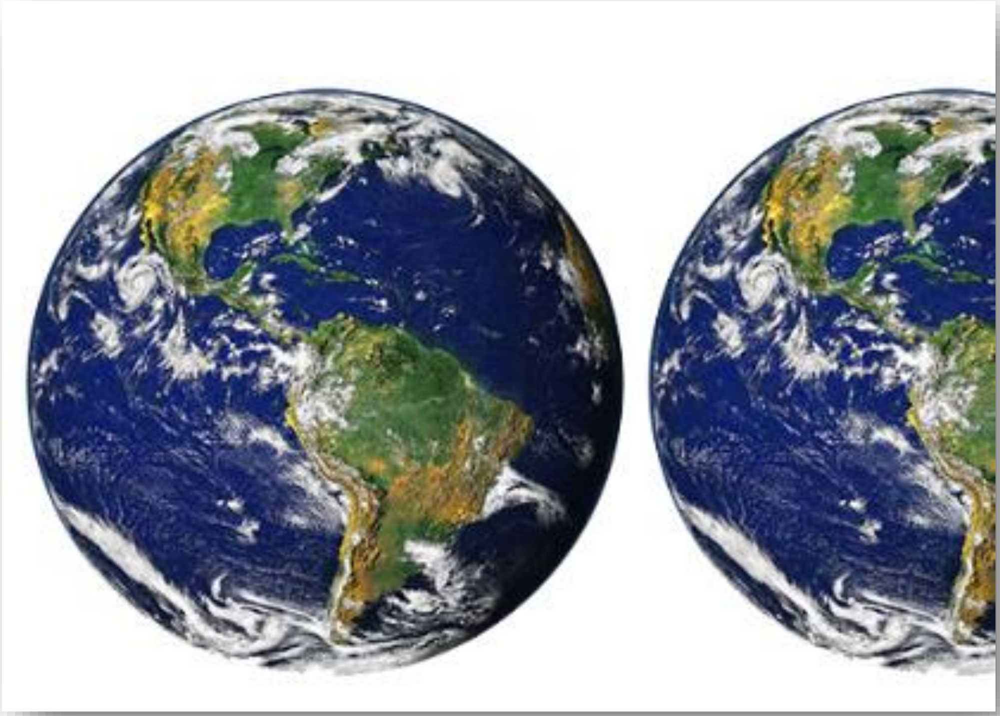
- ✓ Meeting food demand (quantity and quality)
- ✓ Safeguarding people's health
- ✓ Preserving animal welfare
- ✓ Guarantee workers' income
- ✓ Limit the consumption of resources: land, water, etc.
- ✓ Contain the pollution of air, water and soil

# FAO - 17 Sustainable Development Goals - SDGs

# A growing debt

Humanity is currently using the equivalent of 1.6 planets per year to obtain resources and to dispose of waste

This means that the Earth needs a year and a half to regenerate the resources we use in a year



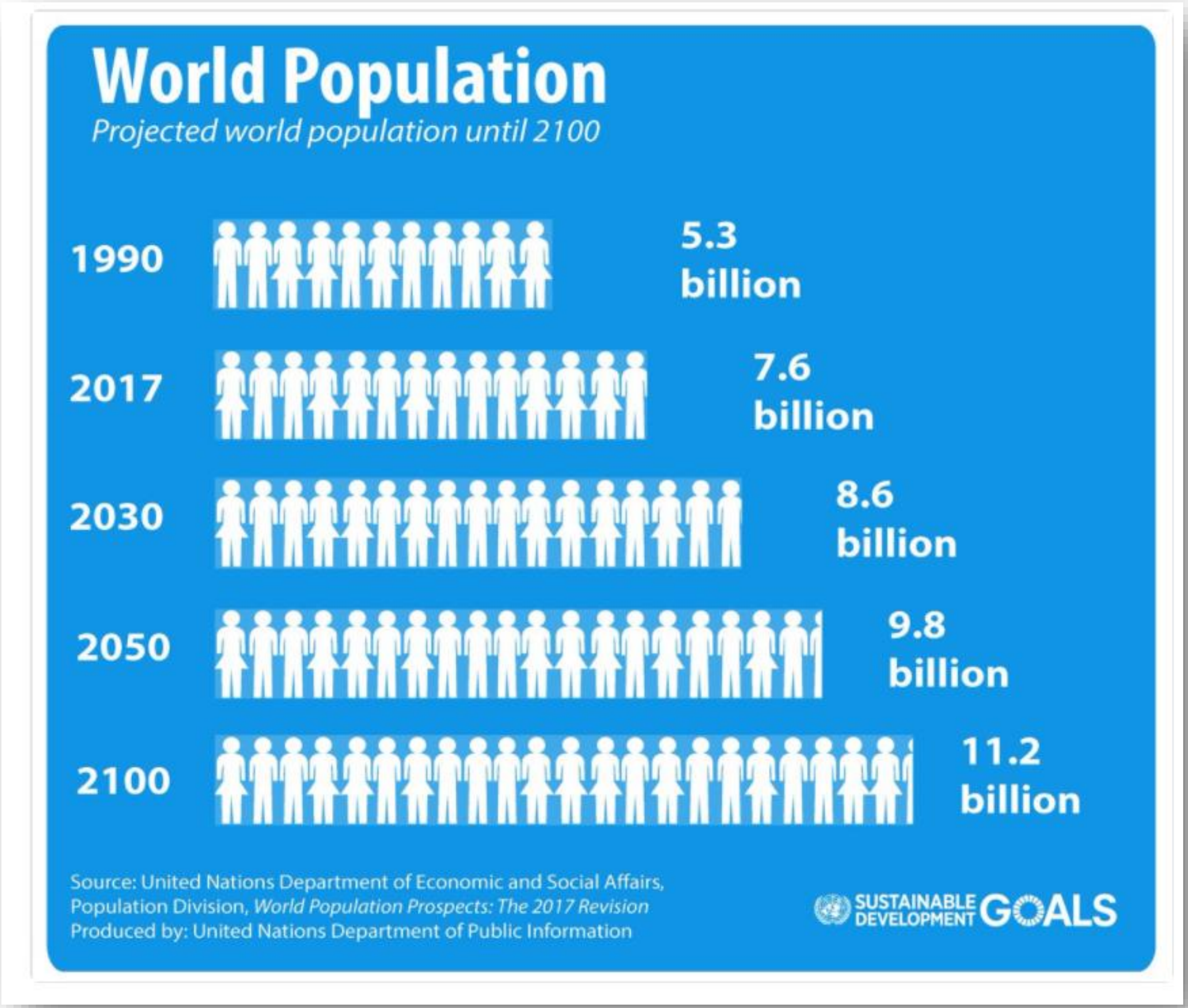
Global Footprint Network, 2016

# The environmental cost of food production

Food production (and consumption) are among the human activities that weigh most on the environment

Greenhouse gas emissions associated with global food production represent more than a quarter of total anthropogenic greenhouse gas emissions
(Poore & Nemecek, 2018)

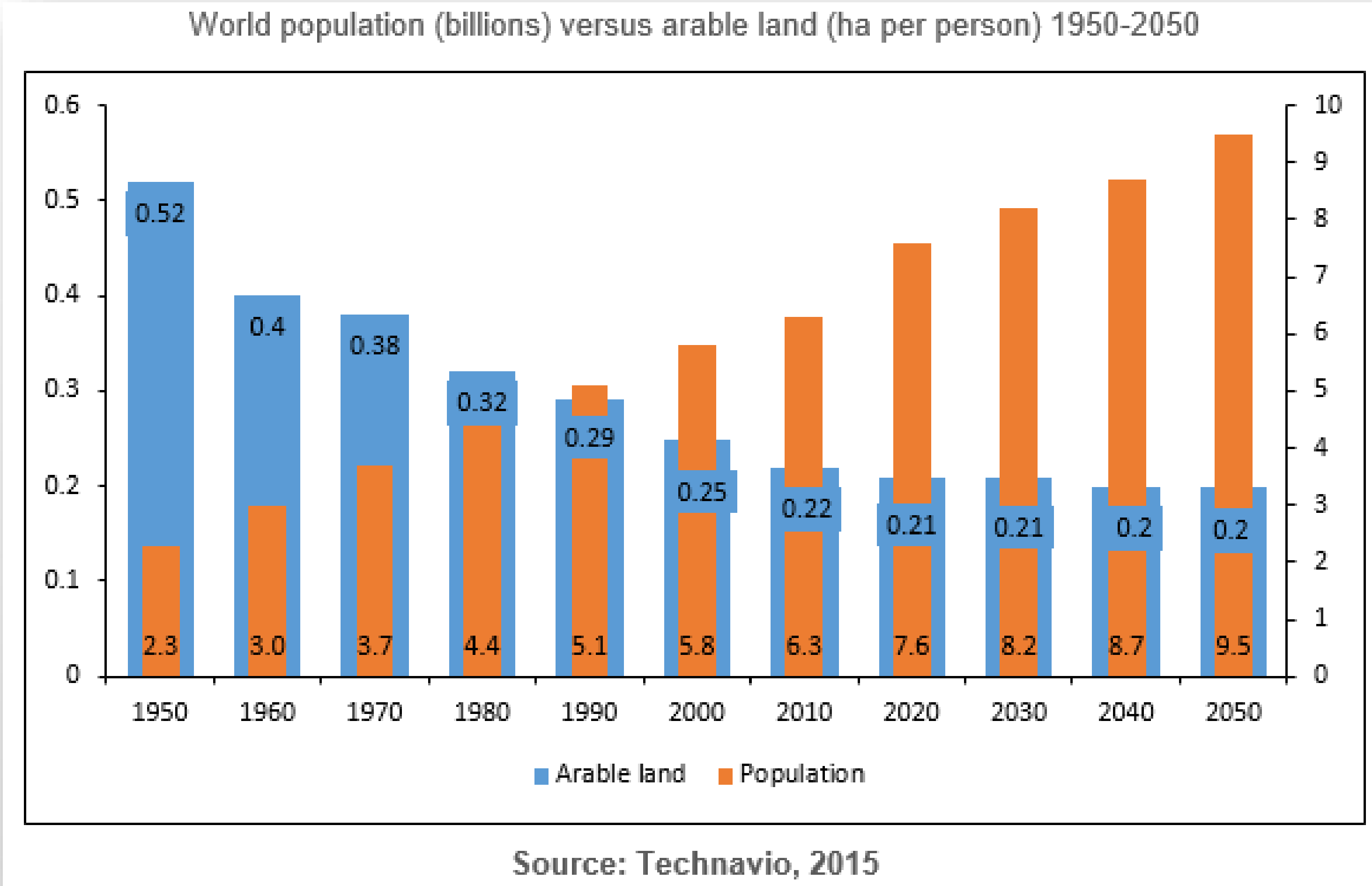
# World population




In 2050 the world population will exceed 9 billion individuals;
in 2100 it will reach 11 billion

FAO, 2017

# Availability of land per capita




To produce food, crop and livestock systems need soil and water, both limited and diminishing resources

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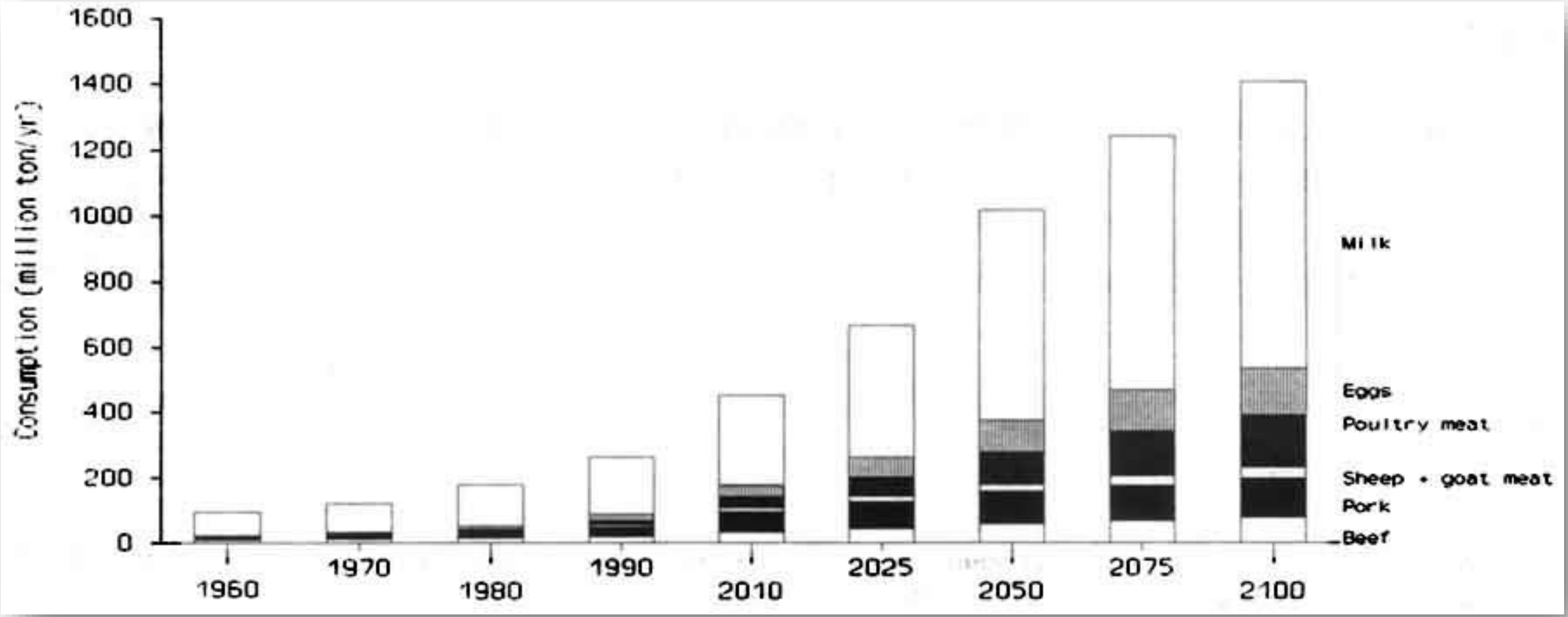
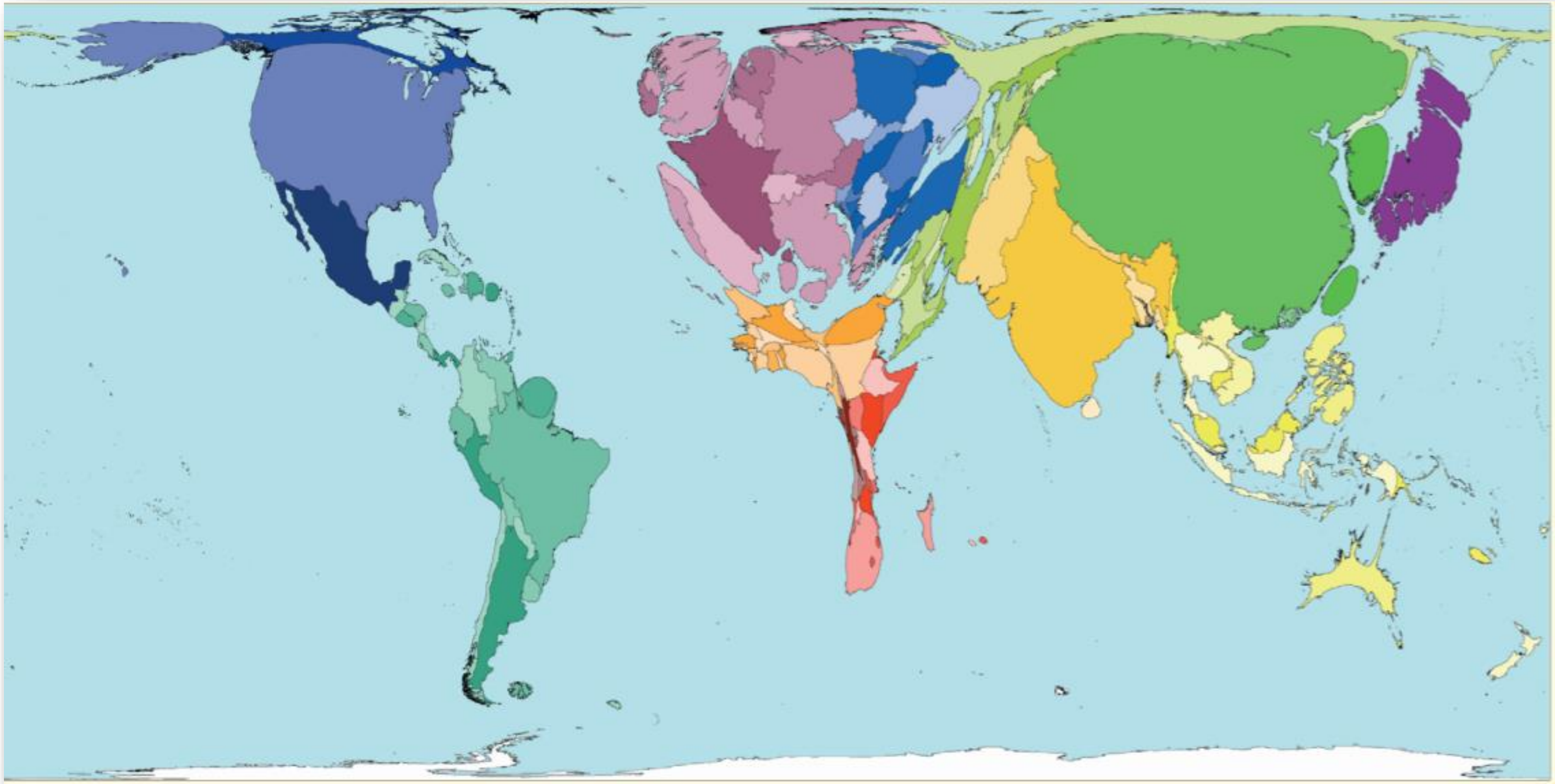
# Demand of animal products




The increase in the world population, together with the increasing per capita income, will lead to a growth in demand for animal products estimated between 70% and 100%, from today to 2050

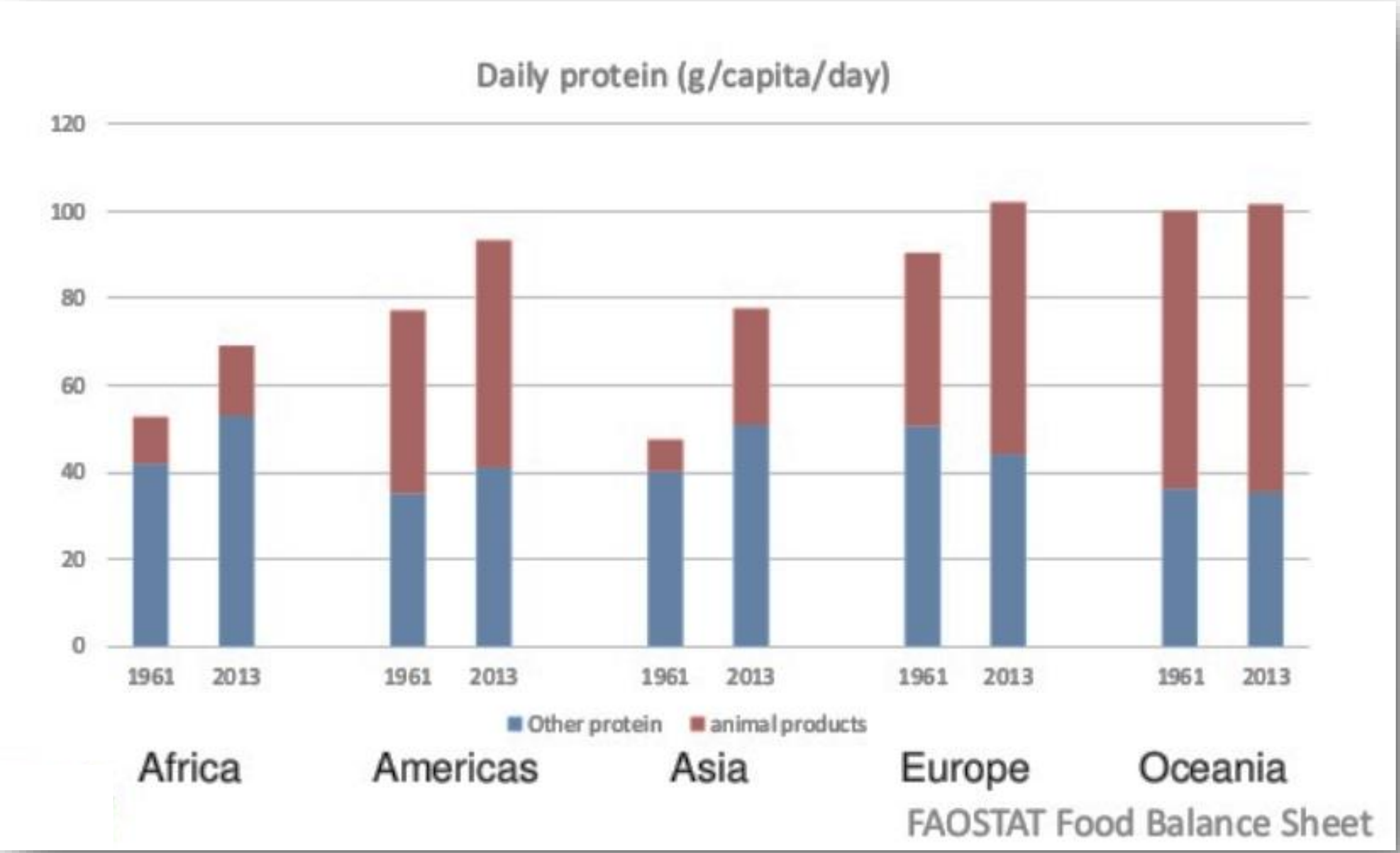
FAO, 2011

# Meat consumed



www.worldmapper.org

# Contribution (%) of food of animal origin to human diet




On average, animal products provide 40% protein supply and 17% energy supply in human diet

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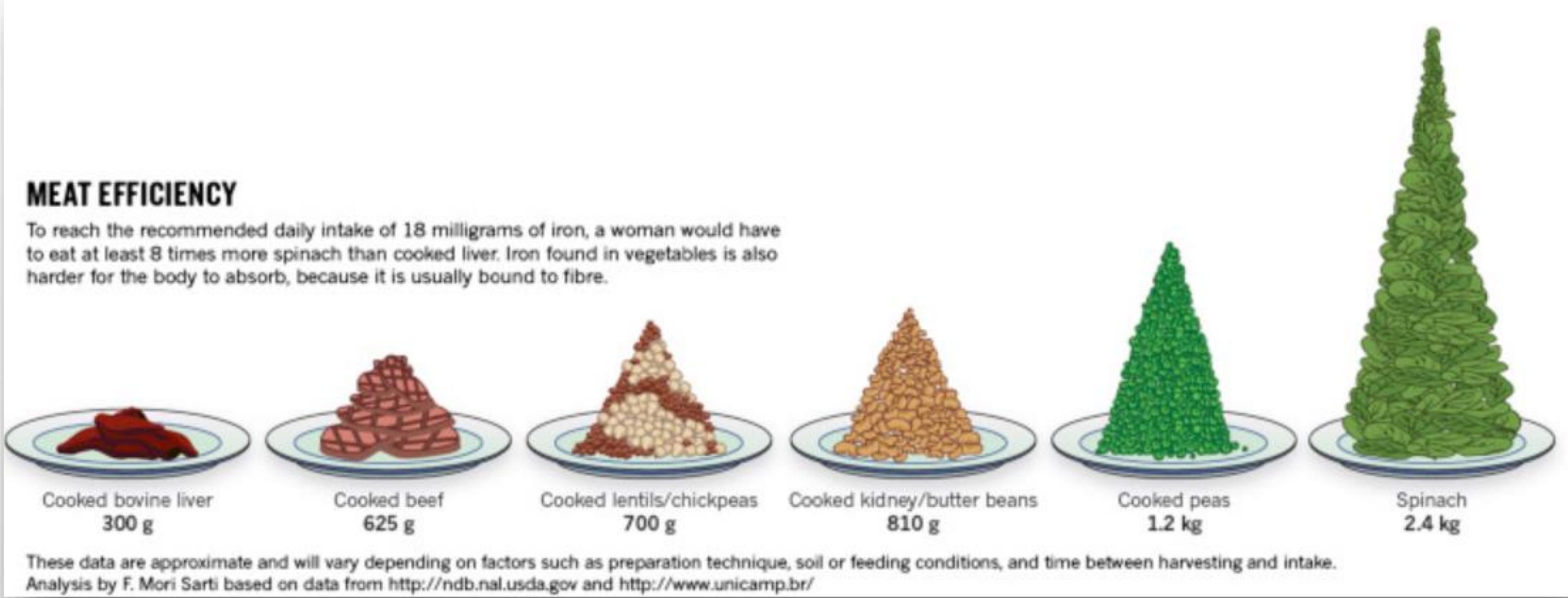
# Food of animal origin

Meat, fish, eggs, milk and cheese supply humans with essential nutrients hard to get from only vegetable-based diets. Among these:

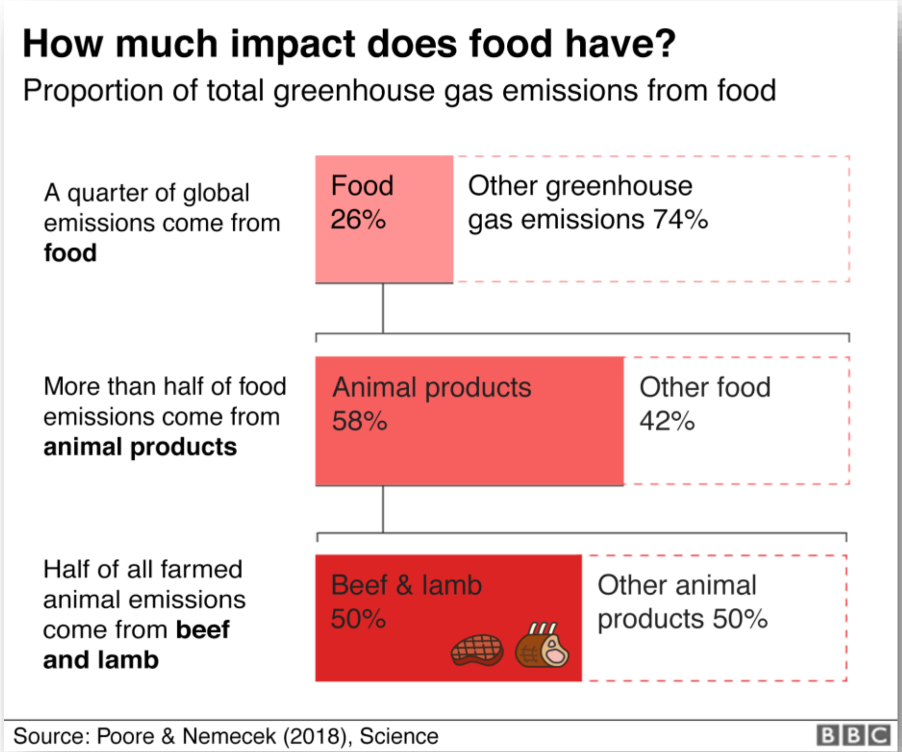
- ✓ essential amino acids (lysine, methionine, threonine, tryptophan, leucine, isoleucine, phenylalanine, histidine and valine)
- ✓ essential fatty acids (e.g. ω3 and CLA)
- ✓ Minerals, trace elements (e.g. Ca, P, Mg, Fe) and vitamins (e.g. B12)



# Animal source food and environmental impact

It is commonly accepted that the production and consumption of food of plant origin entails a much lower environmental cost than that of food of animal origin

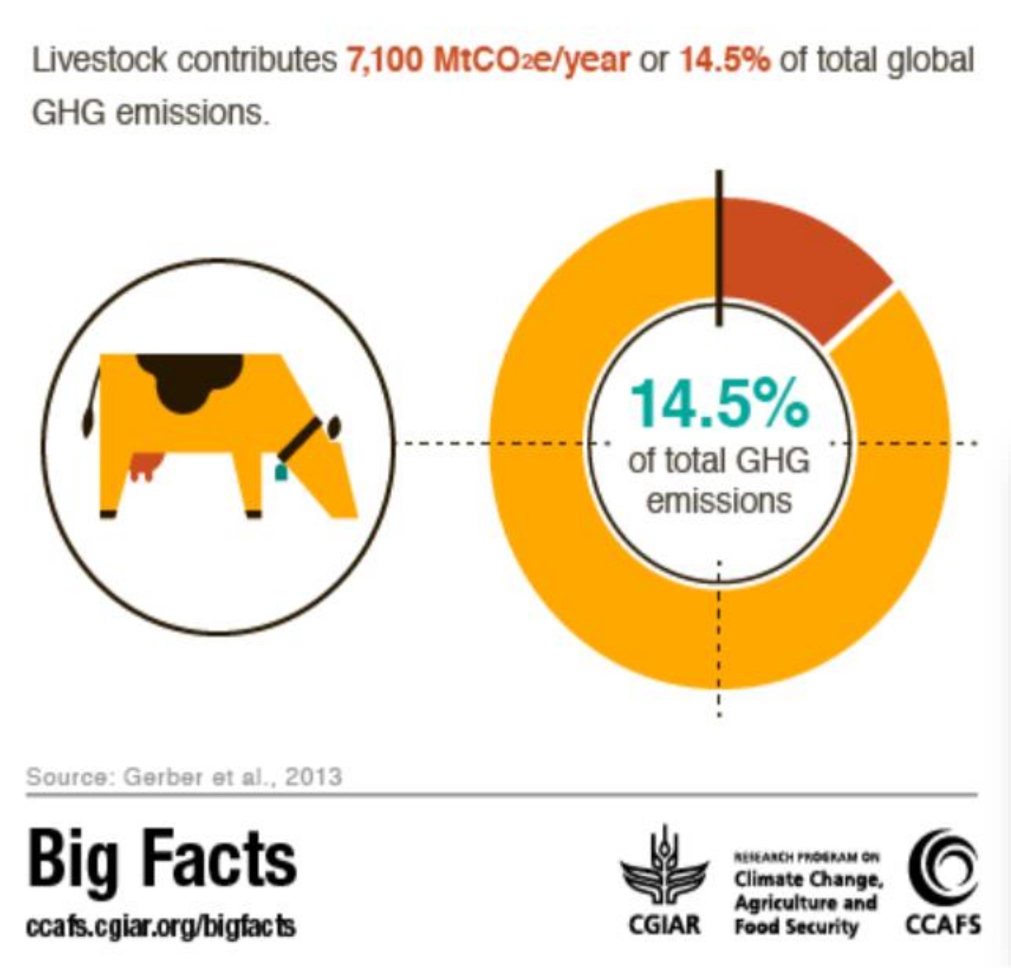
It is believed that a given agricultural area used to grow plant foods can theoretically feed more people than the same area used for the production of food of animal origin



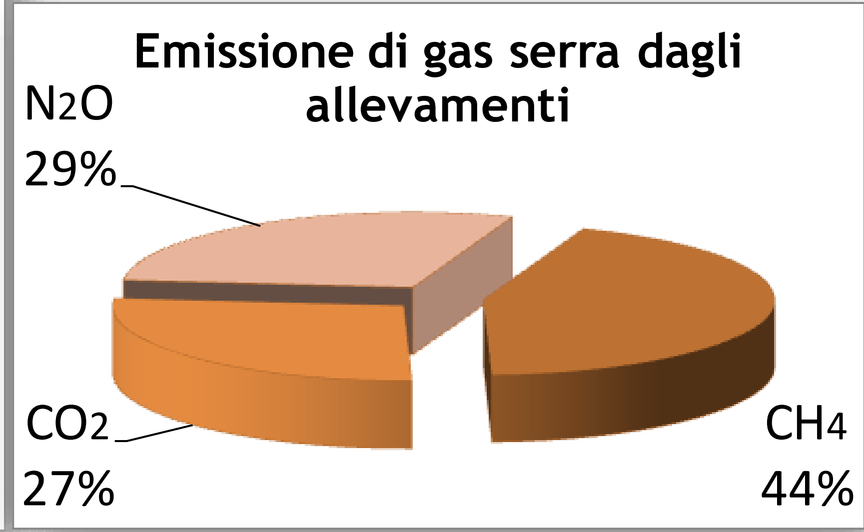
# Environmental impacts of animal productions

- ✓ Greenhouse gas production (global warming)
- ✓ Eutrophication of waters
- ✓ Consumption of non-renewable resources (fossil energy, soil, water)
- ✓ Acidifying emissions
- ✓ Biodiversity reduction
- ✓ …

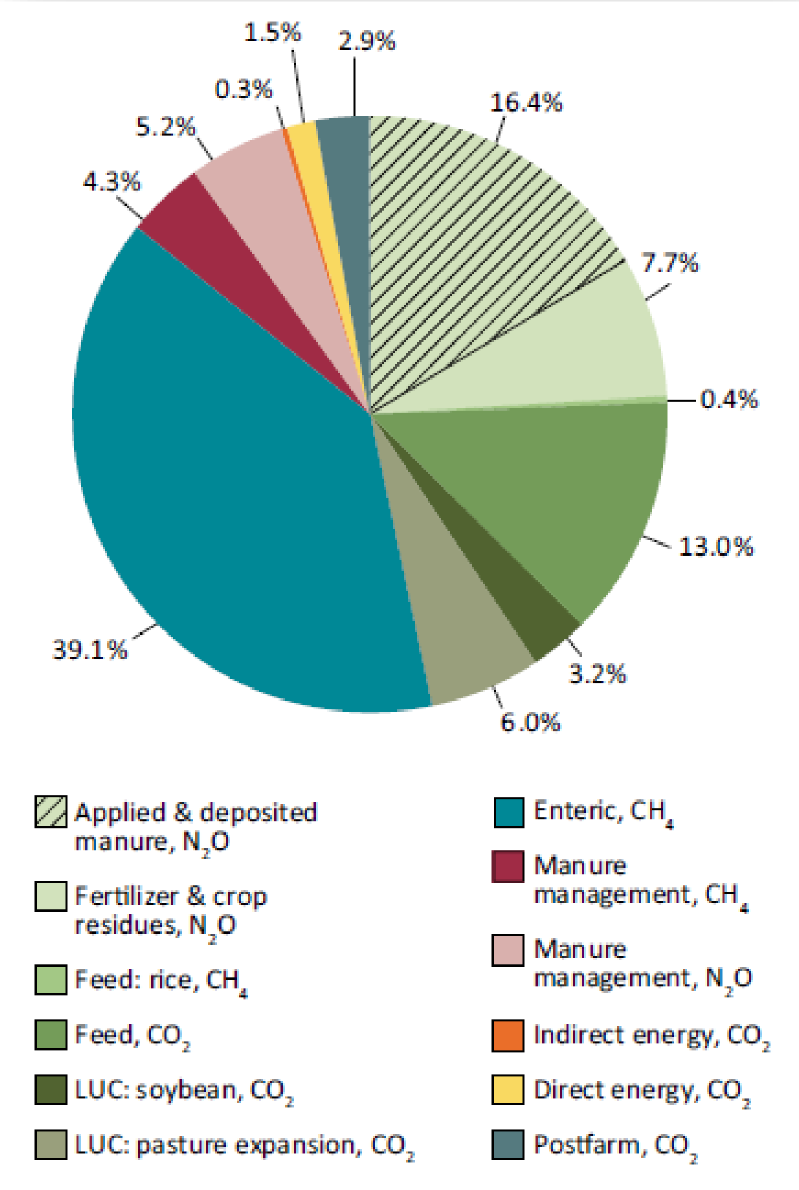
# Animal husbandry and grenhouse gas emissions




Animal husbandry contributes 14.5% to the global release of GHG into the atmosphere resulting from human activities
Gerber et al., 2013



# Global GHG emissions from animal productions



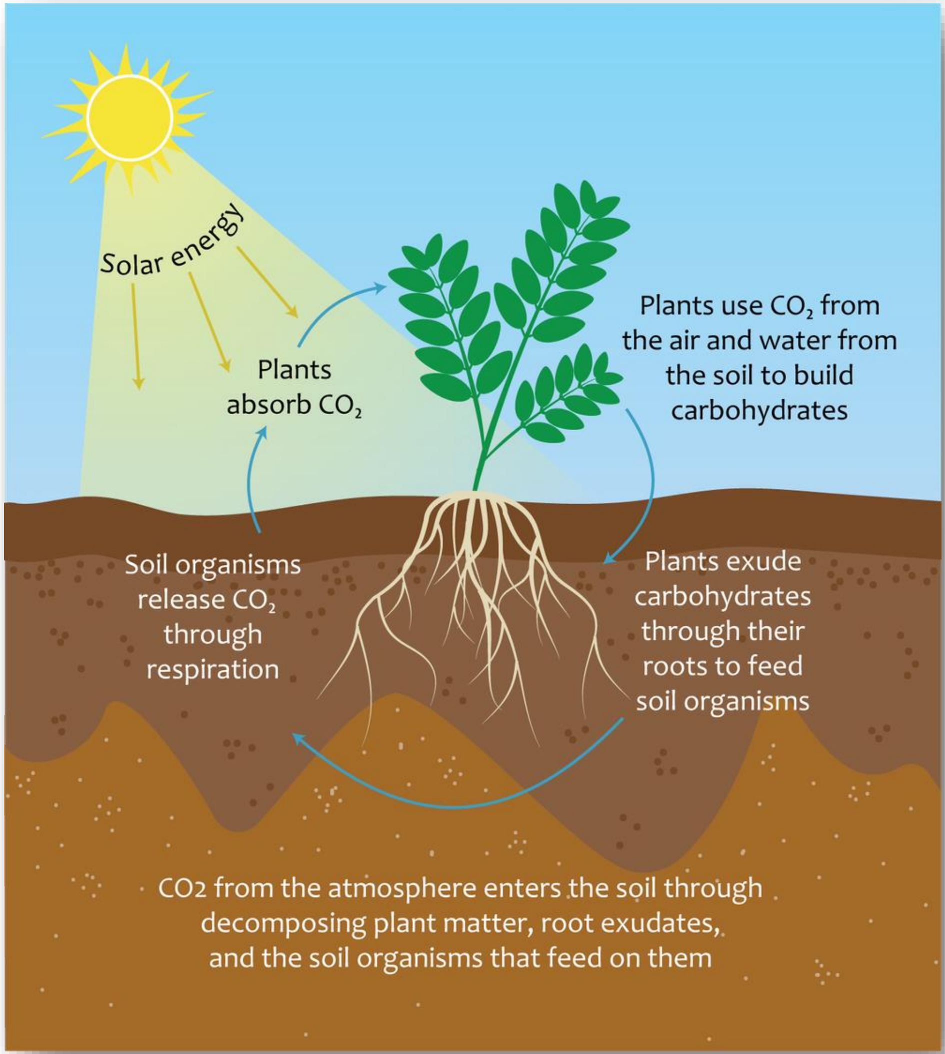

- 45% is given by the cultivation of animal feed
- 39% is given by the methane enteric emission (especially ruminants)
- 3.2% for soybean production and 6% for pasture expansion (LUC)
- Only 2.9% post-farm

FAO, 2013

# Carbon sequestration

- Five main pools of carbon: oceanic, geologic, soil, atmospheric and biotic (Lal, 2008).
- Biotic pool - C absorbed from the atmosphere by plants, algae and bacteria and stored in the living biomass
- Soil pool - parts of plants, dead organisms, animal excrements and microbial biomass
- The organic carbon in the soil pool is 3 times more consistent than the biotic pool (Lal, 2008).
- Both pools constitute a sink of C that is stored for a longer or shorter time.

# Carbon sequestration



# Carbon sequestration

- When natural soils or forests are converted into arable lands, most of the carbon they stored is released drastically into the atmosphere as $CO_2$.
- After that, when the soil is cultivated, agronomic operations cause a continue loss of $CO_2$, due to the mineralization of the soil OM.
- Those emissions are classified as Land Use and Land Use Change (LULUC). The LULUC activities release in the atmosphere 5-5.8 $GtCO_2\ y^{-1}$ (IPCC, 2014).
- Strategies that enhance organic C in the soil and biomass (e.g. permanent pastures instead of arable crops) represent a potential of sequestration of $CO_2$ from the atmosphere (Stefanon et al., 2018).

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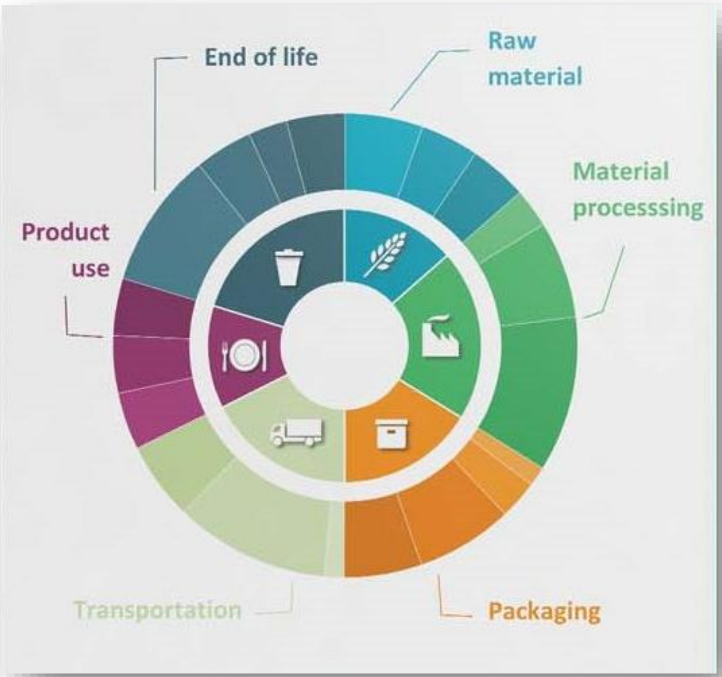
# Life Cycle Assessment




Life Cycle Assessment is a methodology for evaluating the potential environmental impact and resources consumption associated with a production system considering all the stages of a products life from cradle to grave

# Life Cycle Assessment


Life cycle refers to the notion that the systemic assessment of a product or a process requires the evaluation of the impacts of all the stages: raw material extraction and production, manufacture, distribution, use, and disposal (or recycling) including all the intervening transportation steps necessary

Direct and indirect impacts

# Conversion factors - characterization

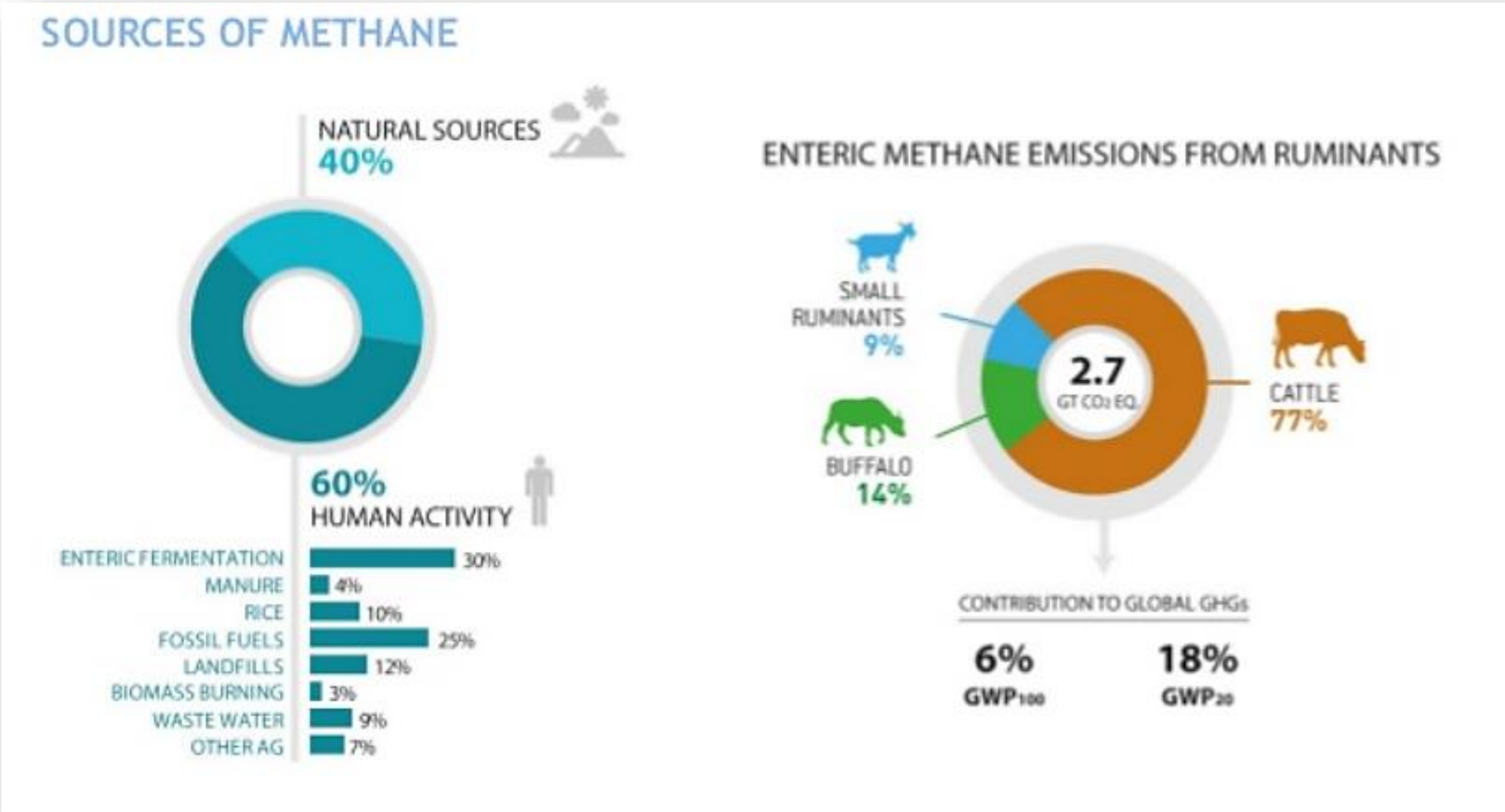
Impacts are expressed as equivalent because different substances have different effects

100-Year Global Warming Potential

| 1 kg of substance | GWP* ($CO_2$-eq) |
|---|---|
| Carbon Dioxide | 1 |
| Carbon Tetrachloride | 1400 |
| CFC 12 | 10,900 |
| Chloroform | 31 |
| Methane | 25 |
| Methyl Bromide | 5 |
| Nitrous Oxide | 298 |
| 1,1,1-Trichloroethane | 146 |

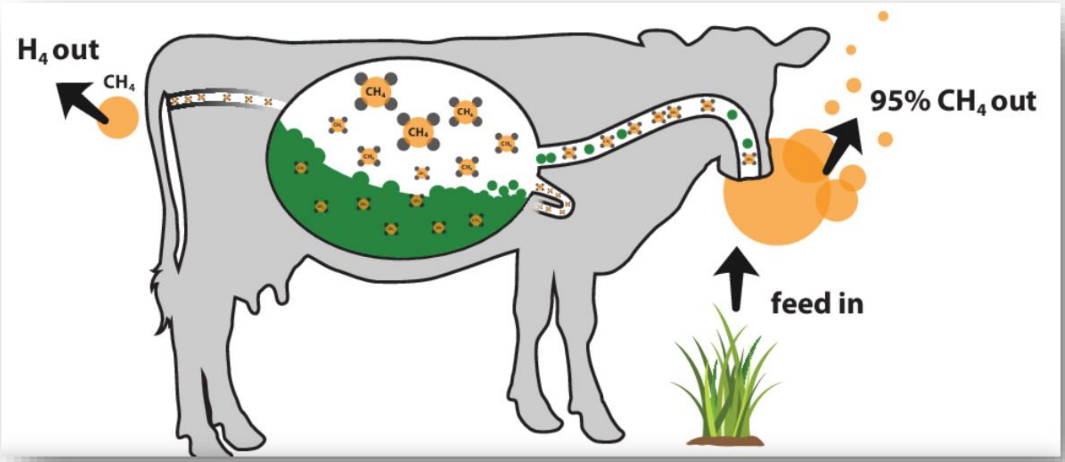
IPCC, 2013

# Sources of methane



# Enteric methane

- Rumen fermentations produce gases: CH4 (30-50%) from Archaea, CO2 (45-65%) from bacteria
- Gases must be eliminated by eructation
- It is a significant energy loss (800-1500 L / d = 8 -15 MJ/d)
- CH4 has 25 times the greenhouse effect of CO2



# GHG emissions from livestock in EU

J.P. Lesschen et al. / Animal Feed Science and Technology 166–167 (2011) 16–28

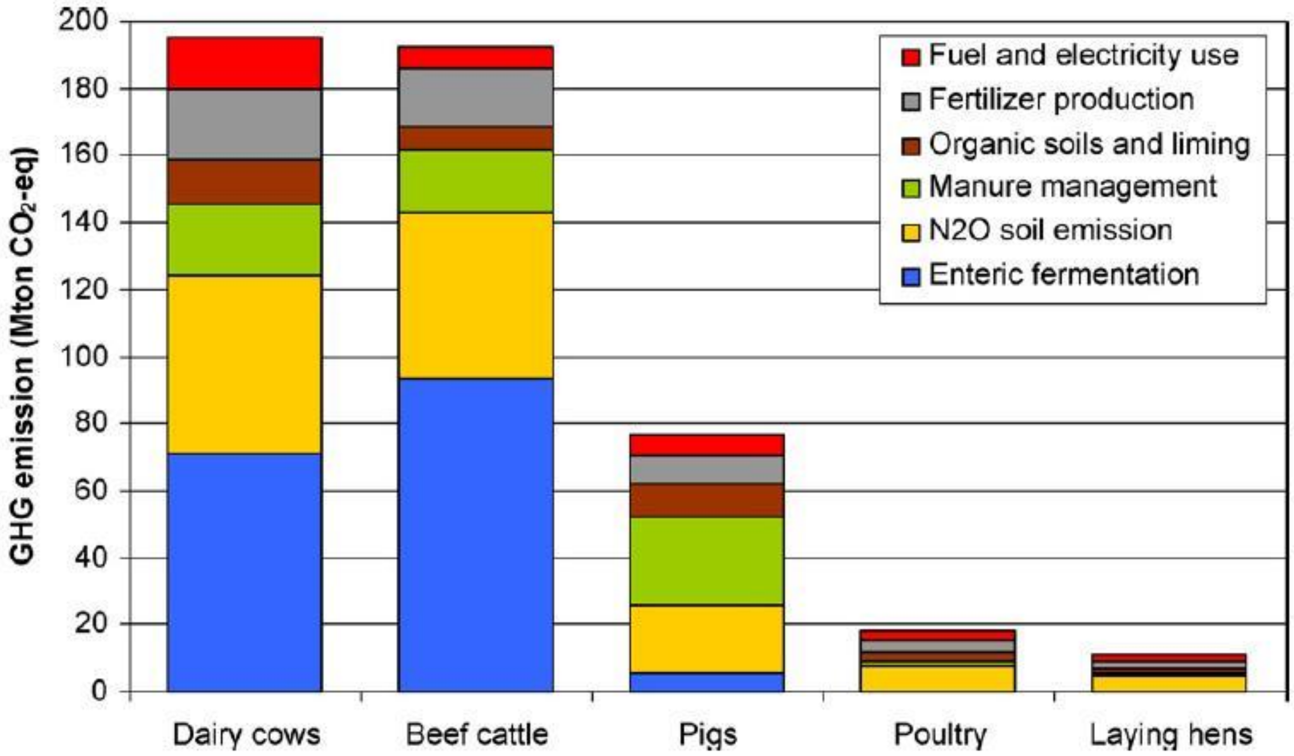
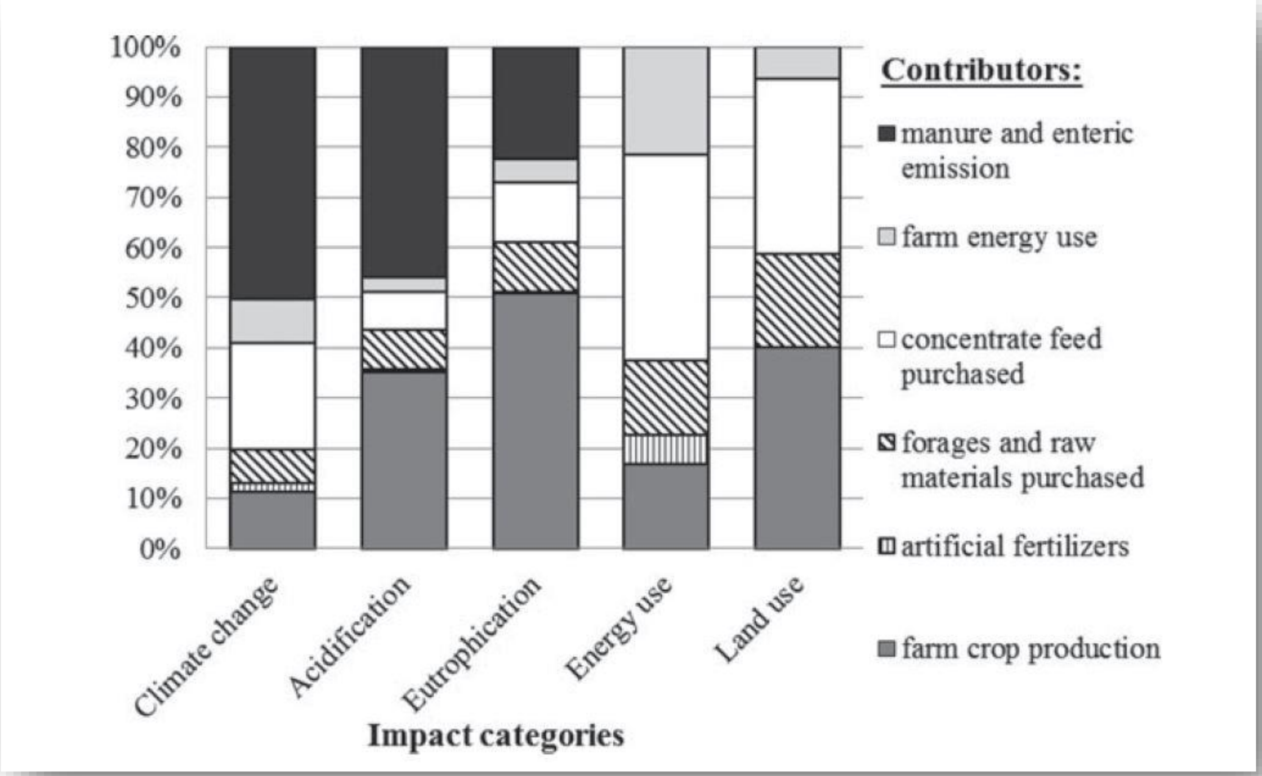



**Fig. 7.** Total greenhouse gas emissions from the various emission sources associated with livestock production in the EU-27.

# Main contributions (%) to the impacts of milk production

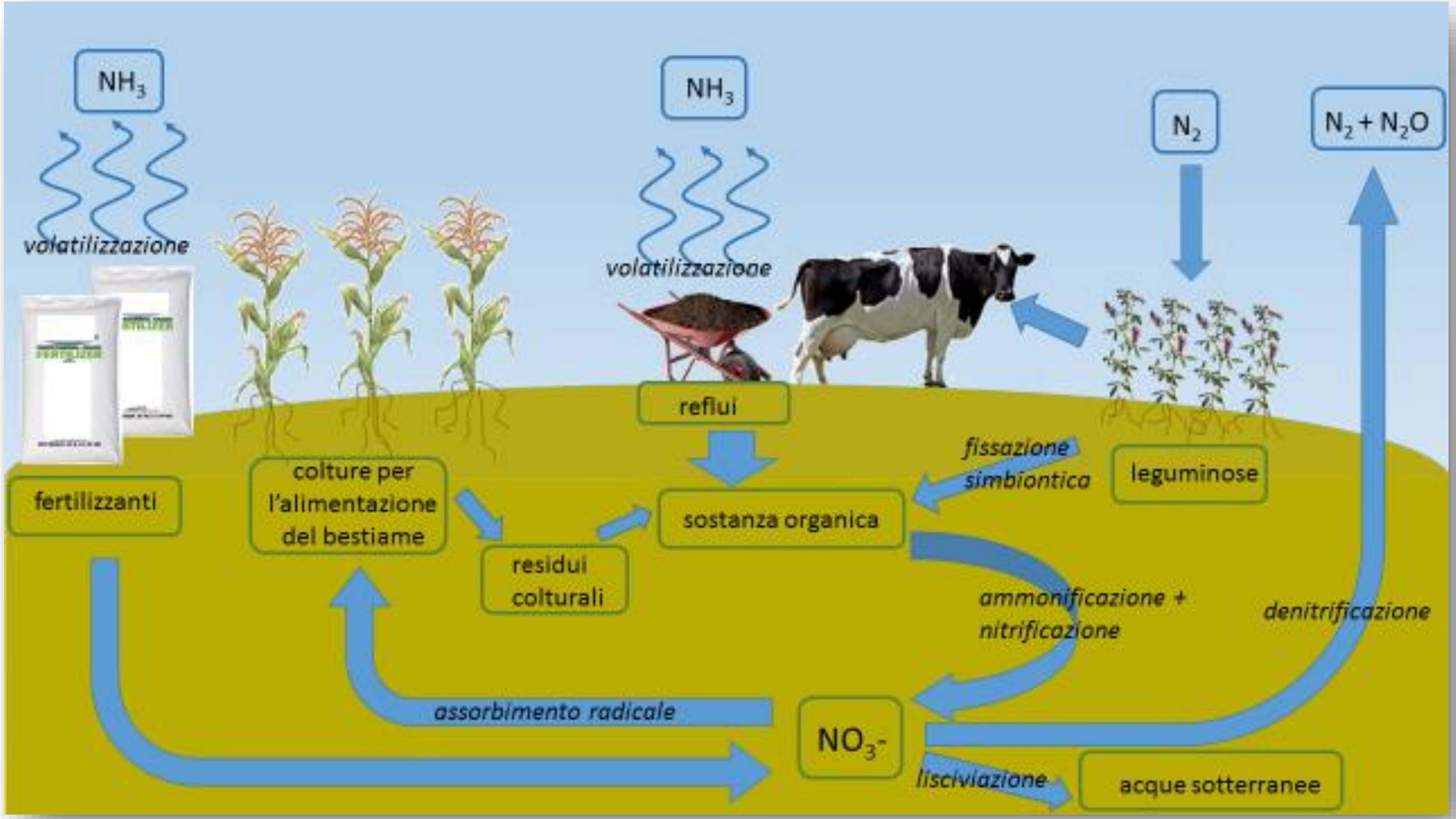
GHG emissions from the production, processing and transportation of livestock feed represent on average 45% of emissions from the livestock sector




Gerber et al., 2013

Guerci et al., 2013

# Eutrophication and acidification

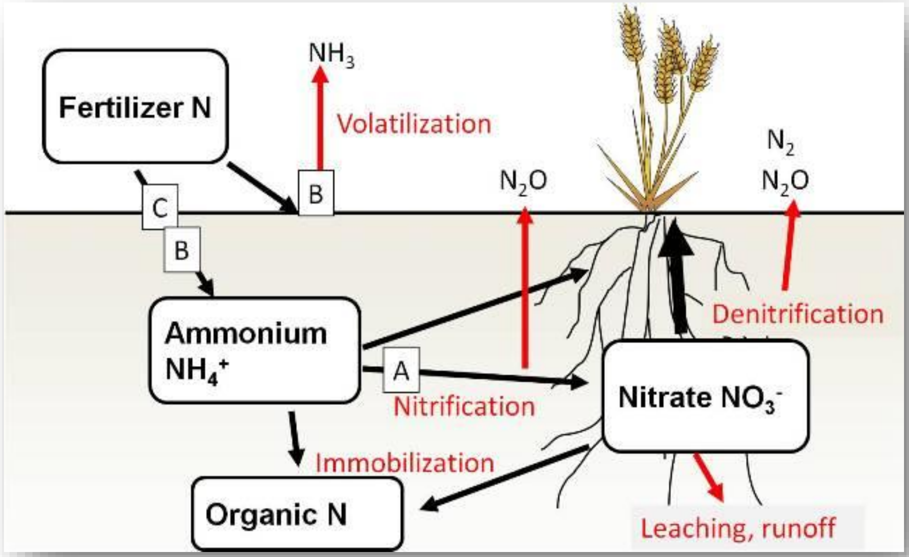



In Europe animal husbandry contributes 41% to the release of N in surface and groundwater e 82% of the release of anthropogenic NH3 into the atmosphere Leip, 2015

# Water eutrophication

- Caused by nitrogen and phosphorus released on agricultural soils in the form of mineral fertilizers and animal wastes in excess compared to the utilization ability by the plants, or to the immobilization capability of the soil

- Nutrients accumulate in the soil and tend to transfer to surface waters (runoff; N and P) and groundwater (leaching; N)





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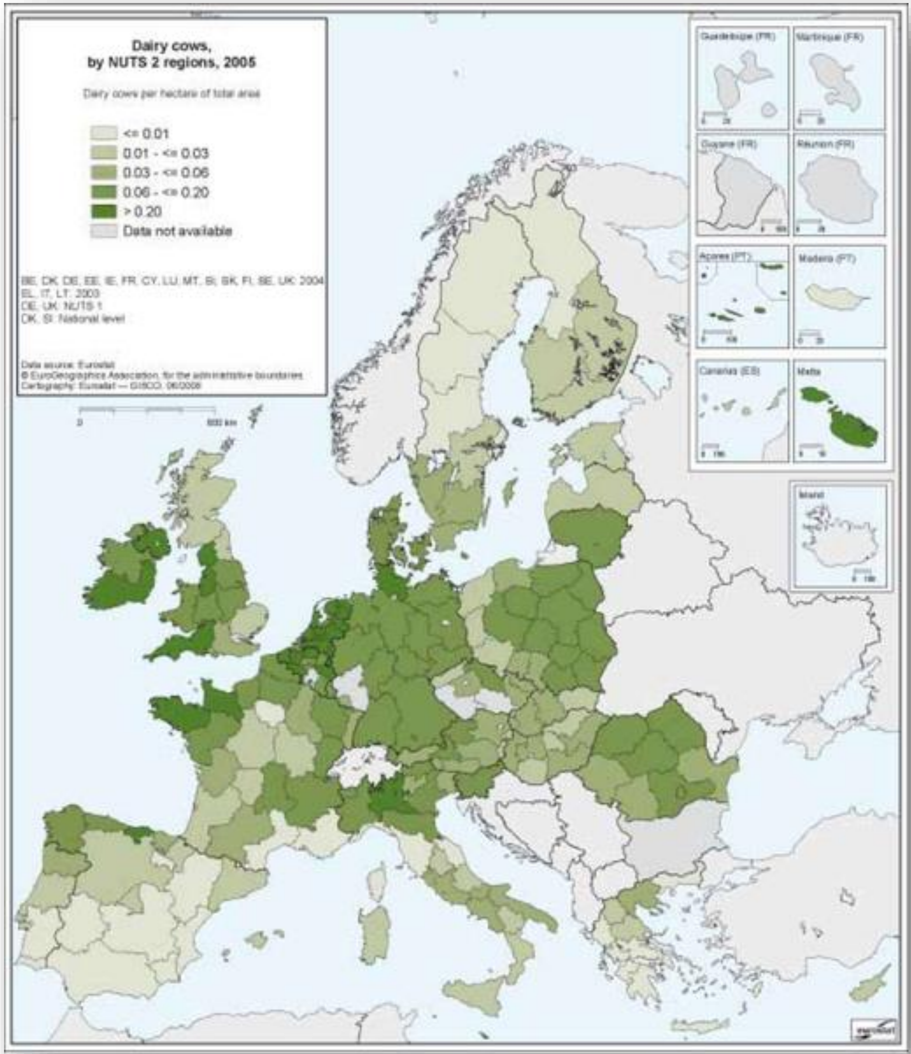
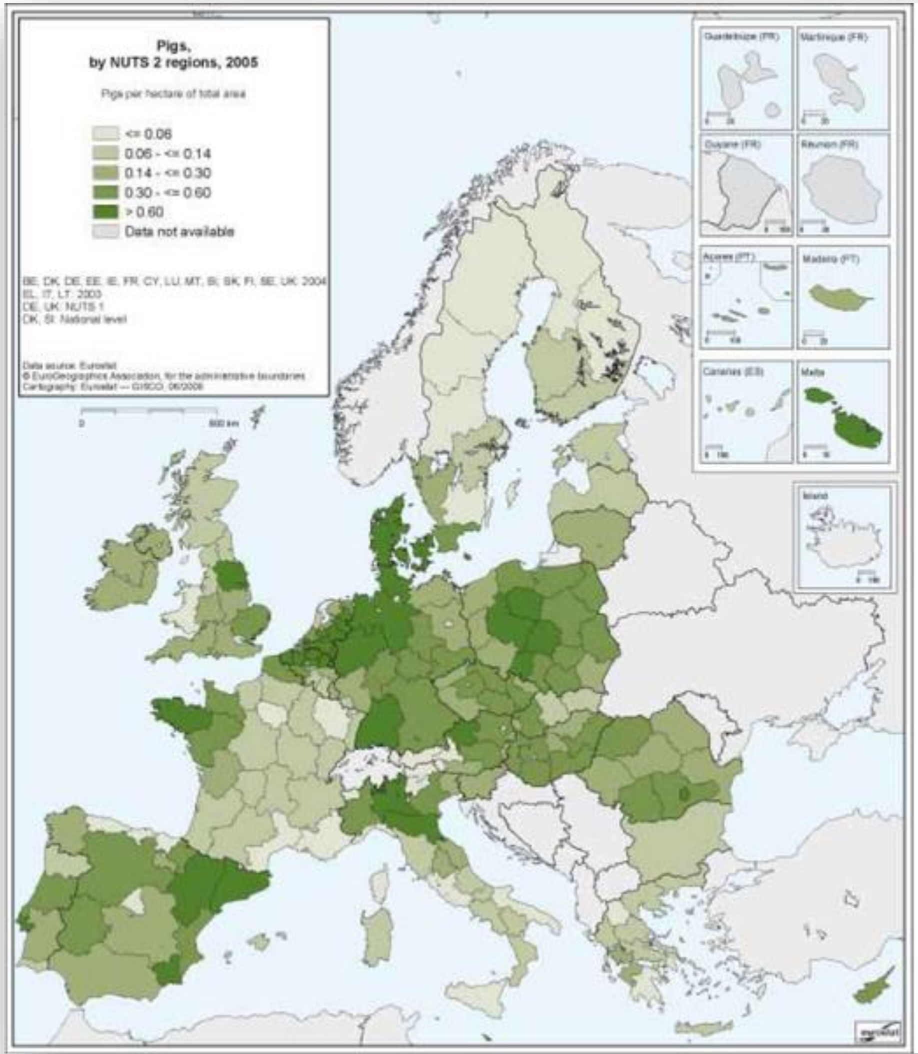
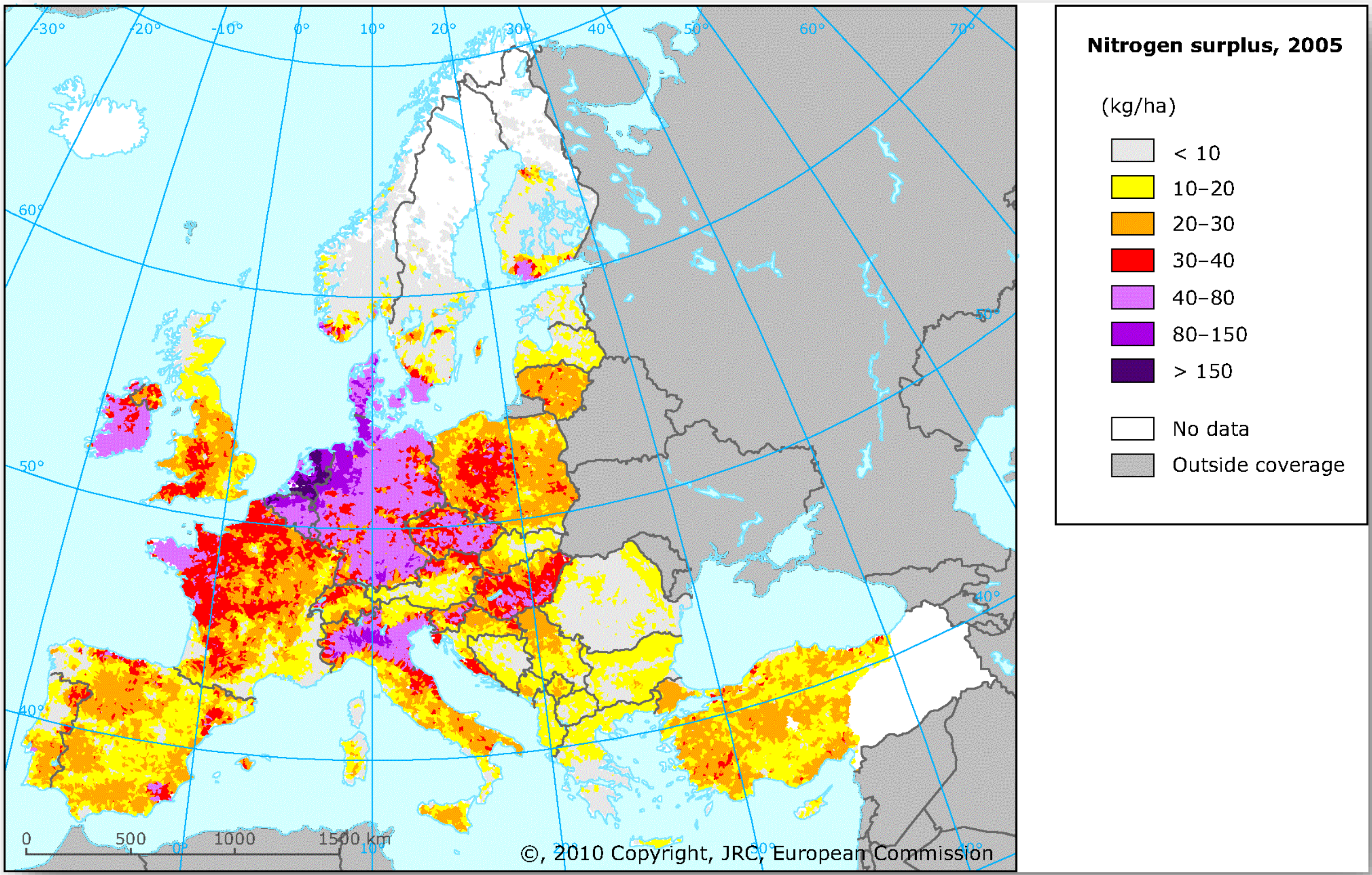
# Dairy cow and pig densities per ha in EU

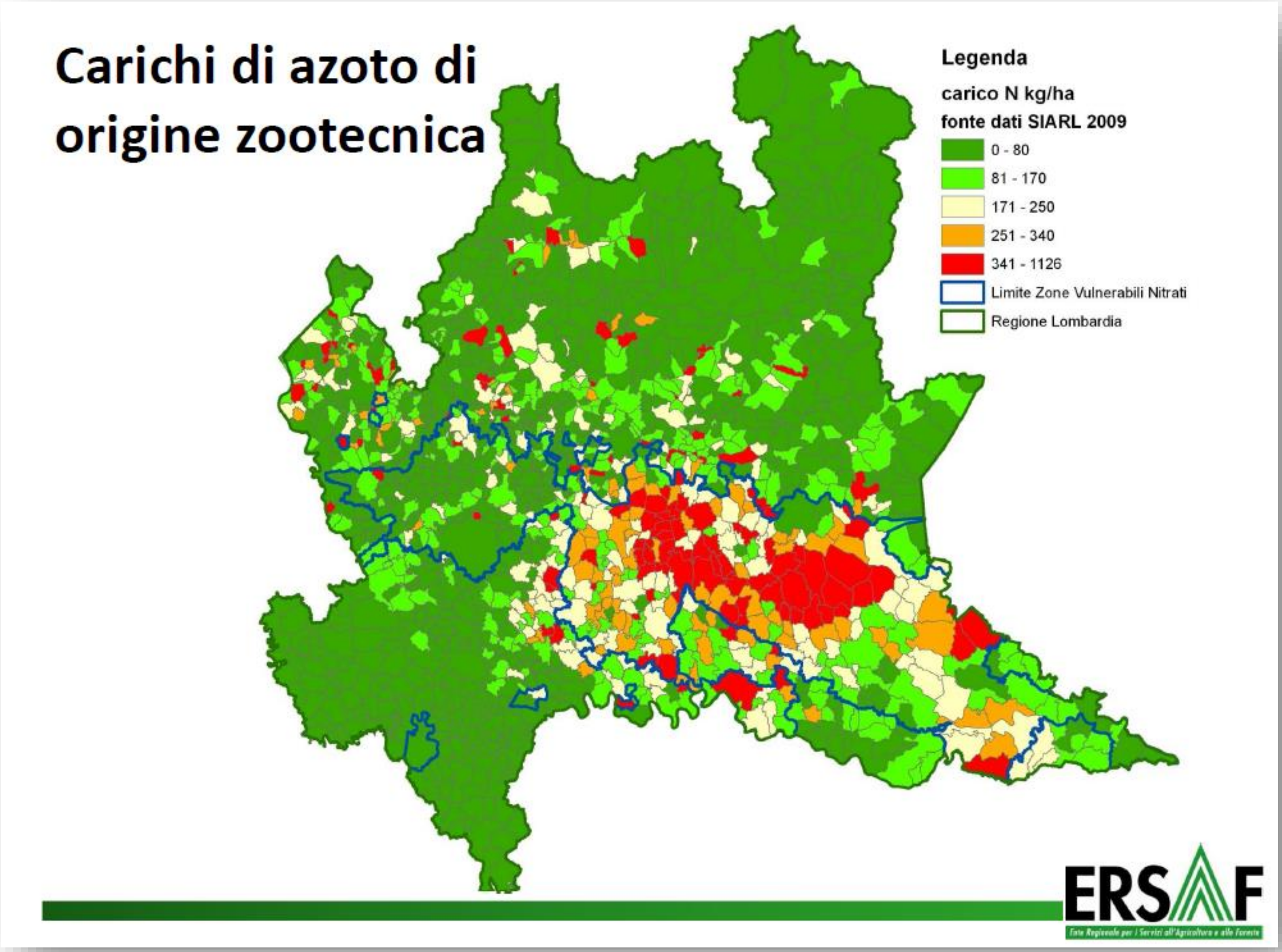


# N surplus per ha per year



# N surplus per ha per year



# Ammonia emissions

NH3 emissions cause acid rain and nitrogen deposition on soils and waters (acidification) and particulates (PM2.5)

More than 90% of anthropic ammonia derives from agriculture: animal manure and nitrogen fertilizers

Most of the ammonia agriculture is emitted from animal manure (urease)

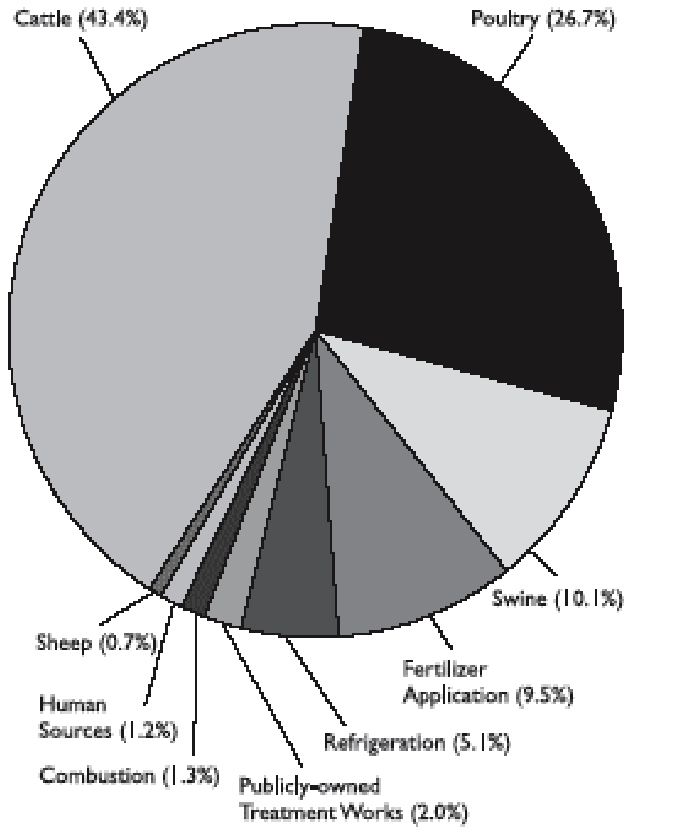
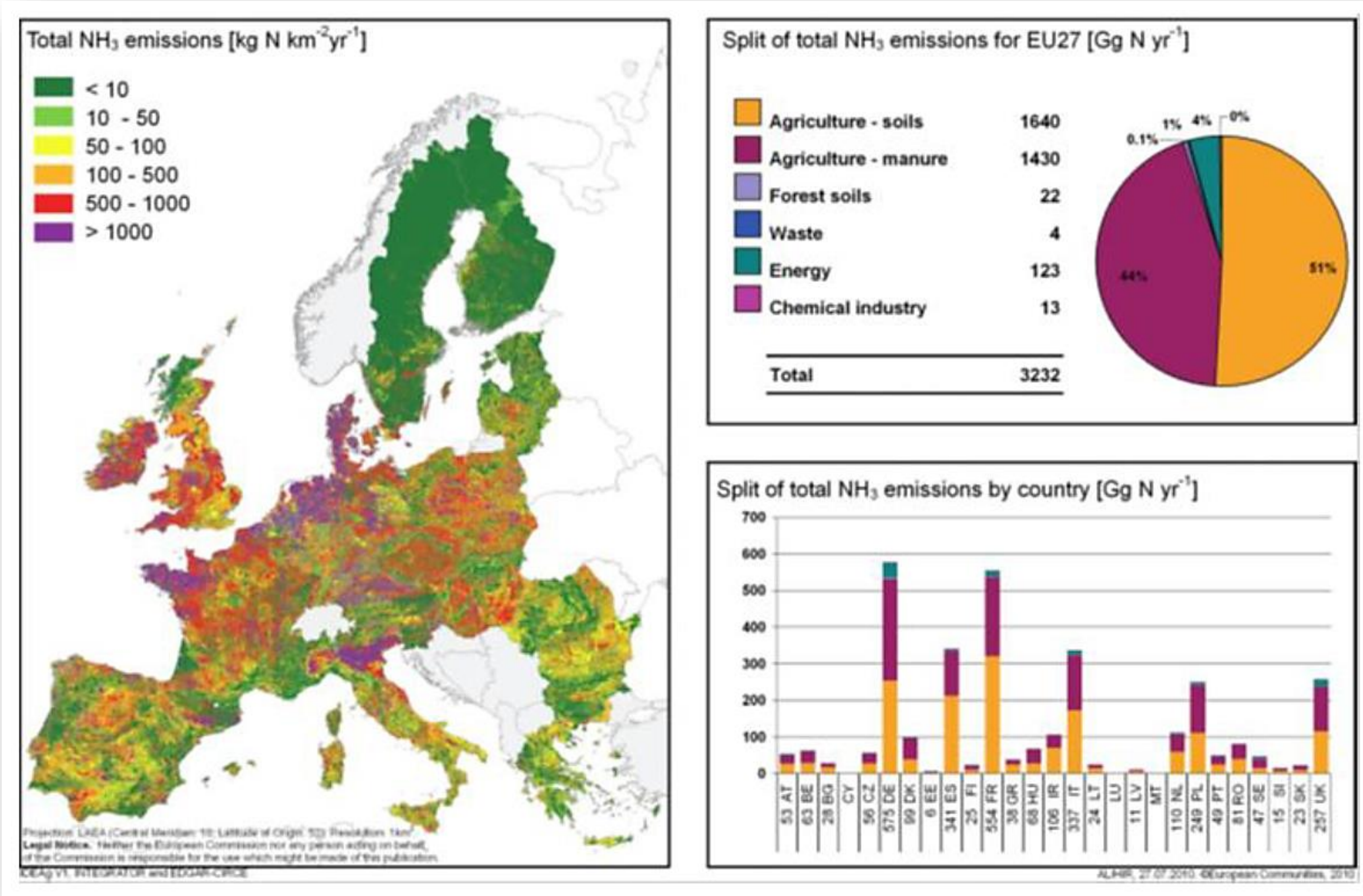



Figure 2. Estimates of ammonia emissions from man-made sources in the U.S. in 1994 (Battye et al., 1994).

# Ammonia emissions

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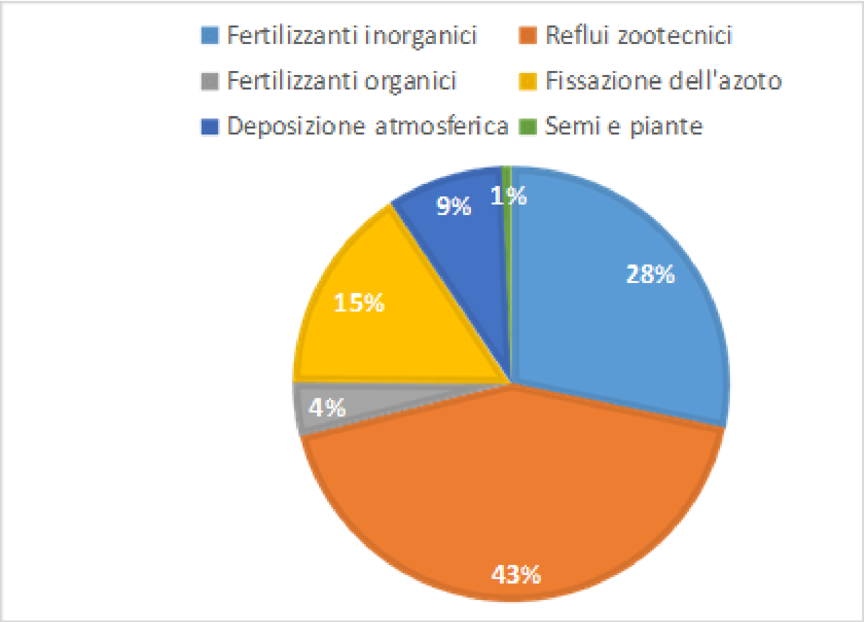
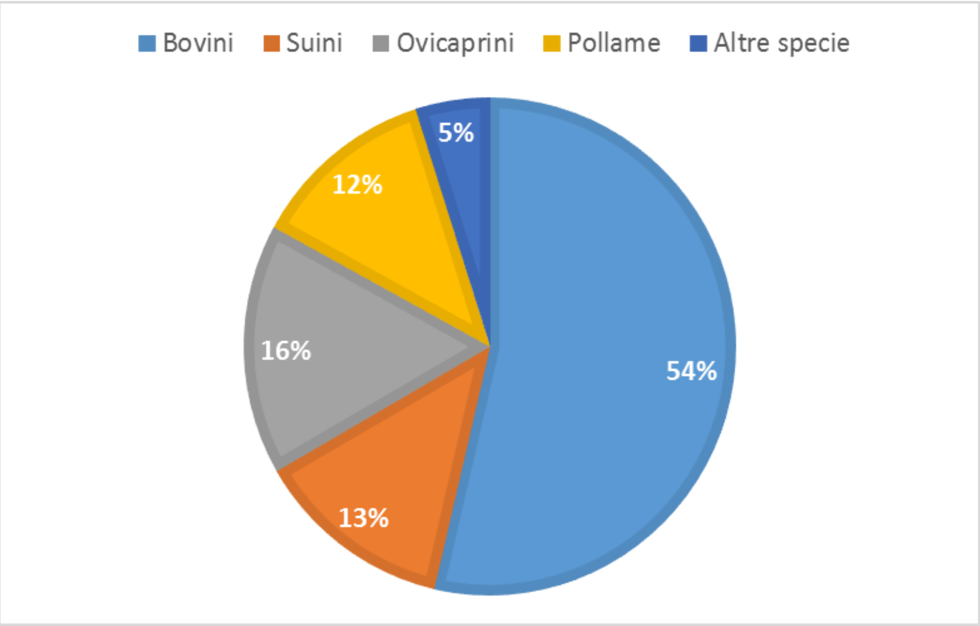
# Contribution of N sources on Italian soils




Eurostat, 2017
Gross Nutrient Balance

# Acidification

Soil and water problems

- SOx (mainly sulfur dioxide) (not from agriculture)
- SO2 sulfur dioxide (not from agriculture)
- NOx = NO monoxide and NO2 dioxide from NH3

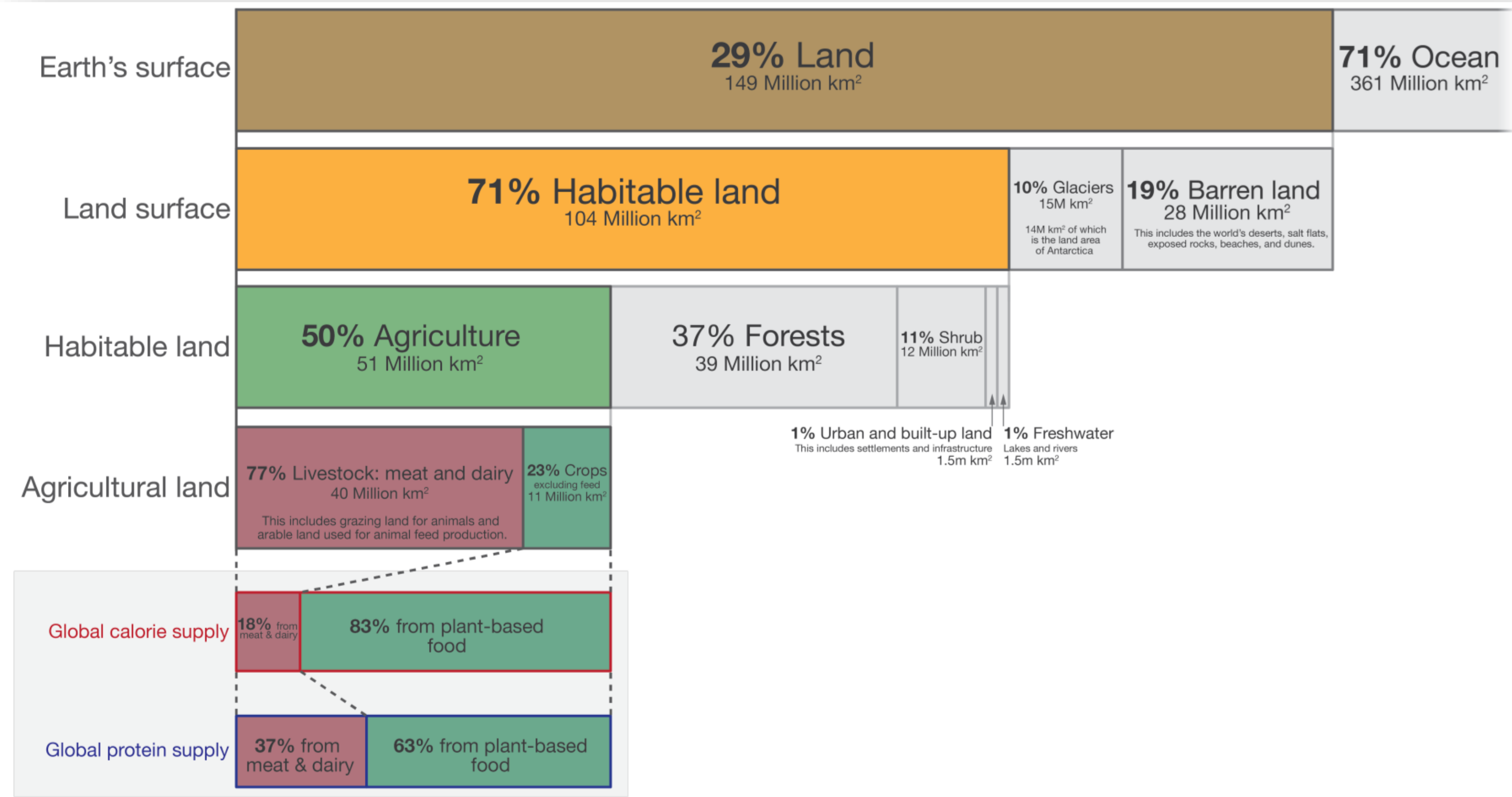
From these molecules, sulfuric and nitric acid are generated in the atmosphere, which precipitate by gravity or by rain (pH modification in soil and water)

# Land use

The total area occupied by pastures and crops intended for the production of animal feed is equivalent to 30% of the earth's surface not covered by ice and about 70% of the world's agricultural area

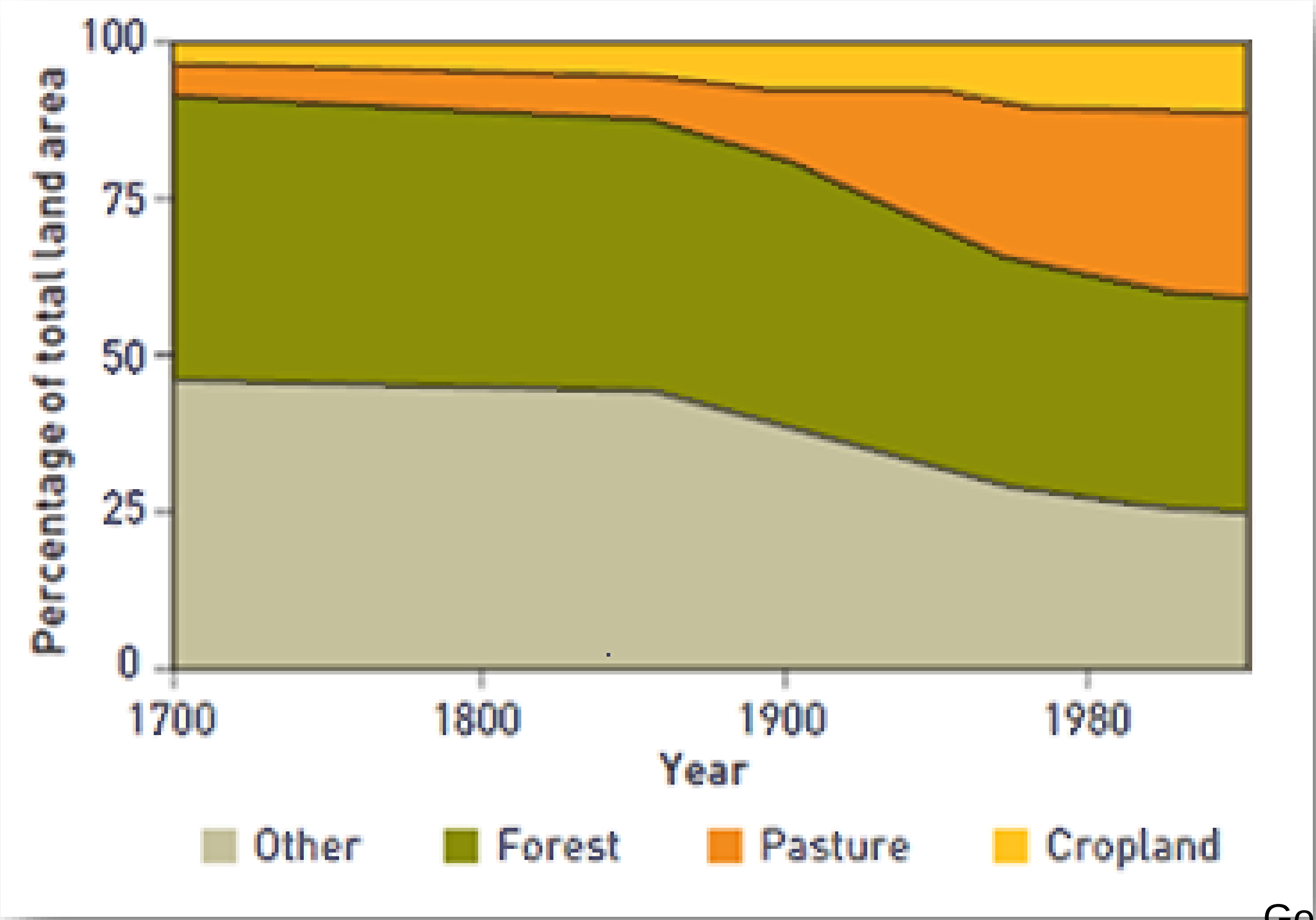

Steinfeld et al., 2006

# Global land use for food production



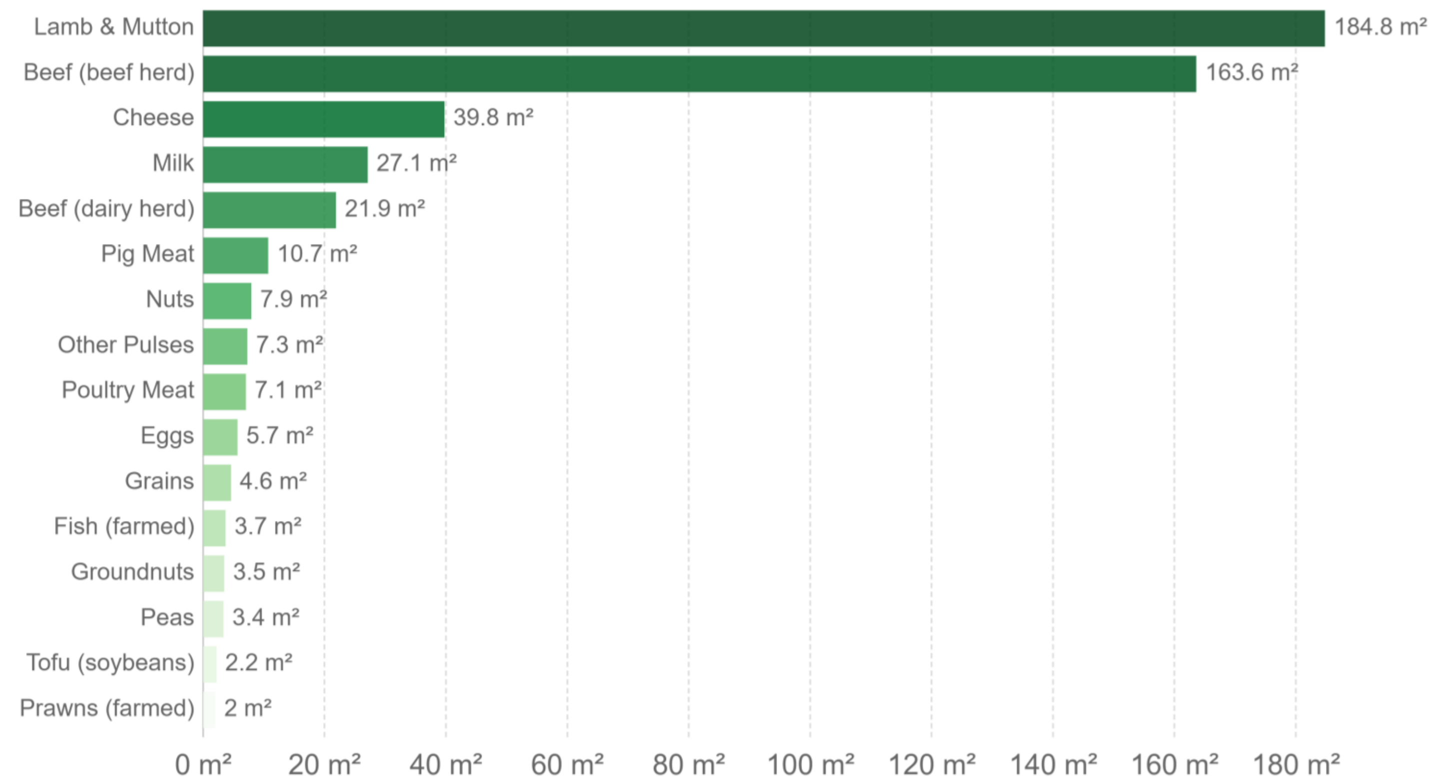

Data source: UN Food and Agriculture Organization (FAO)
OurWorldinData.org – Research and data to make progress against the world's largest problems.

# Land use change from 1700 to 1995



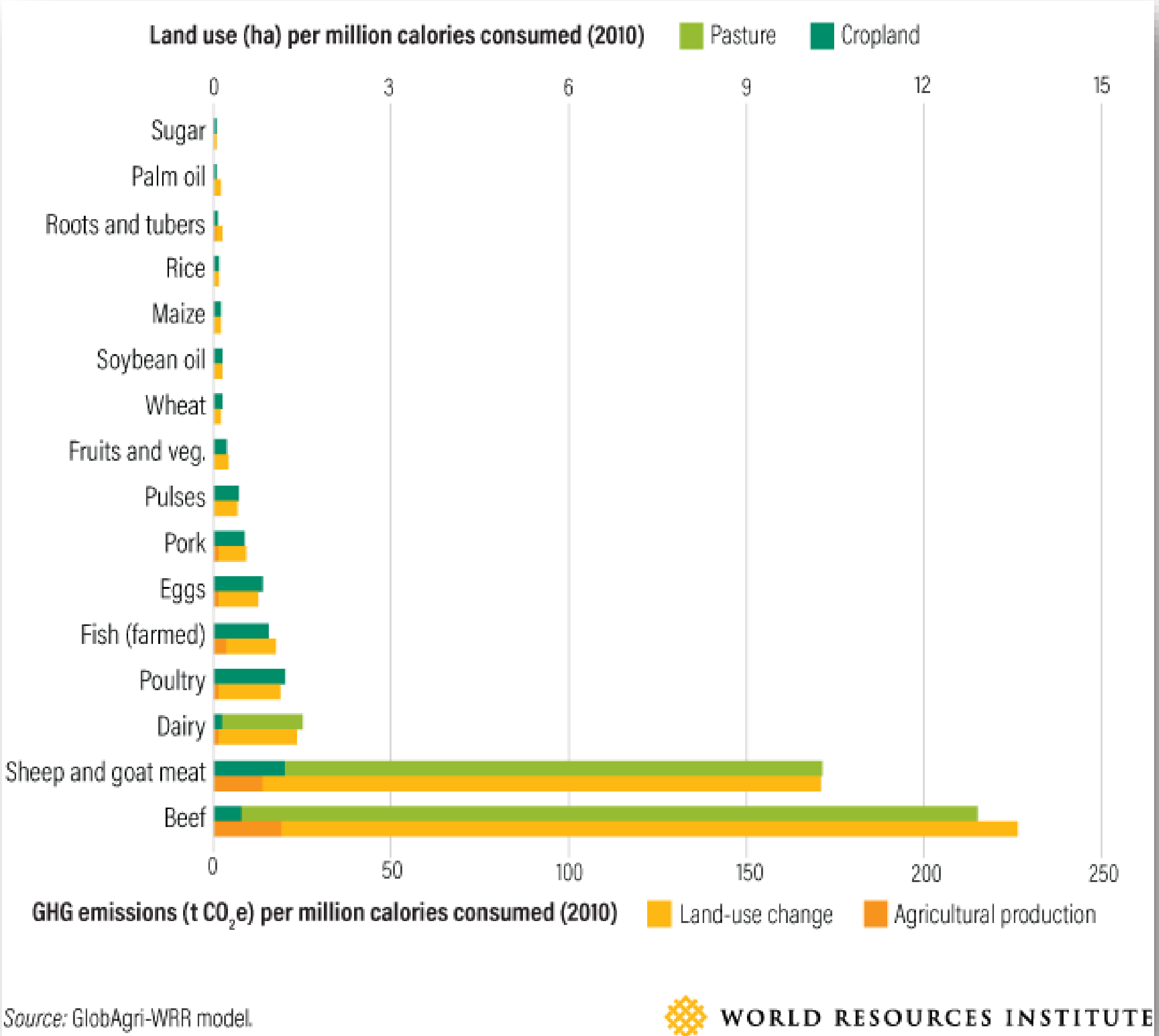

Goldewijk, 1997

# Land use per 100 g protein




Source: Poore, J., & Nemecek, T. (2018). Additional calculations by Our World in Data.
Note: Data represents the global average land use of food products based on a large meta-analysis of food production covering 38,700 commercially viable farms in 119 countries.
OurWorldInData.org/environmental-impacts-of-food • CC BY

# Land use

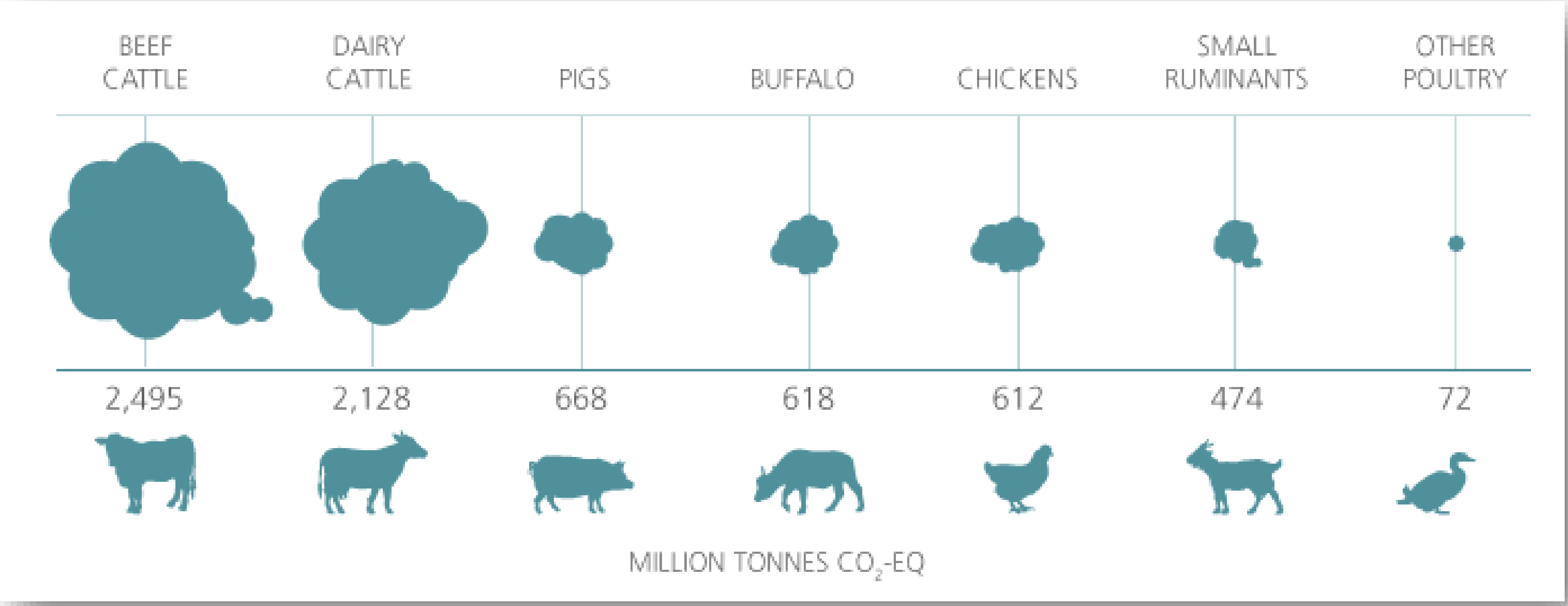

Land use (ha) per million calories consumed (2010)
Pasture
Cropland
0
3
6
9
12
15
Sugar
Palm oil
Roots and tubers
Rice
Maize
Soybean oil
Wheat
Fruits and veg.
Pulses
Pork
Eggs
Fish (farmed)
Poultry
Dairy
Sheep and goat meat
Beef
0
50
100
150
200
250
GHG emissions (t $CO_2e$) per million calories consumed (2010)
Land-use change
Agricultural production
Source: GlobAgri-WRR model.
WORLD RESOURCES INSTITUTE

# Ask a question

# Factors influencing environmental impact of animal products

Species
Feed efficiency
Productivity
Feeding treatments
By-products for animal feeding
Herd efficiency
Croppping systems
Husbandry systems
(Functional unit)
….

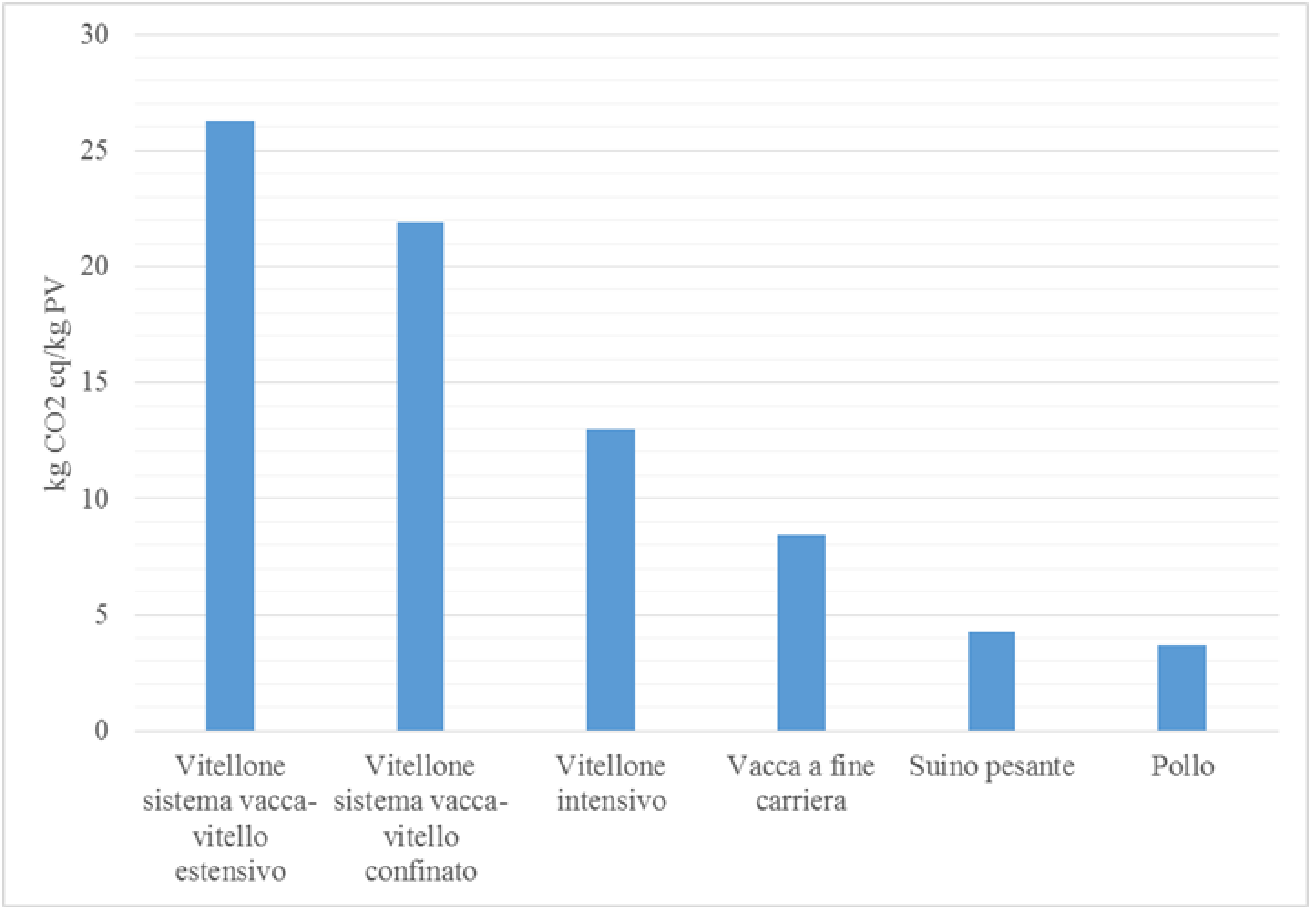
# Global GHG emissions from different animal species




Cattle (for meat and dairy) are the main responsible for the greenhouse gas emissions of the livestock sector (65%)

Gerber et al., 2013

# GHG emissions per kg live weight

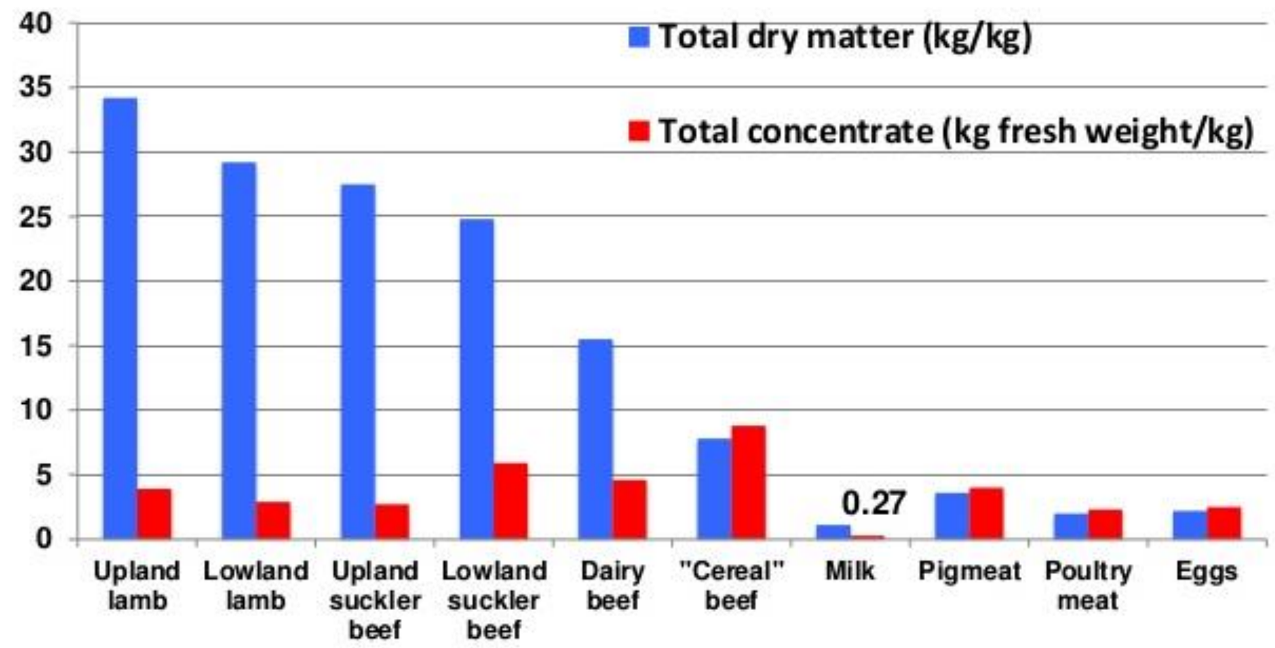



Berton et al. 2017; Bragaglio et al. 2017; Bacenetti et al. 2016; Bava et al. 2017; Cesari et al. 2017

# GHG emissions for livestock products in CO2eq per kg of product


de Vries and de Boer, 2009

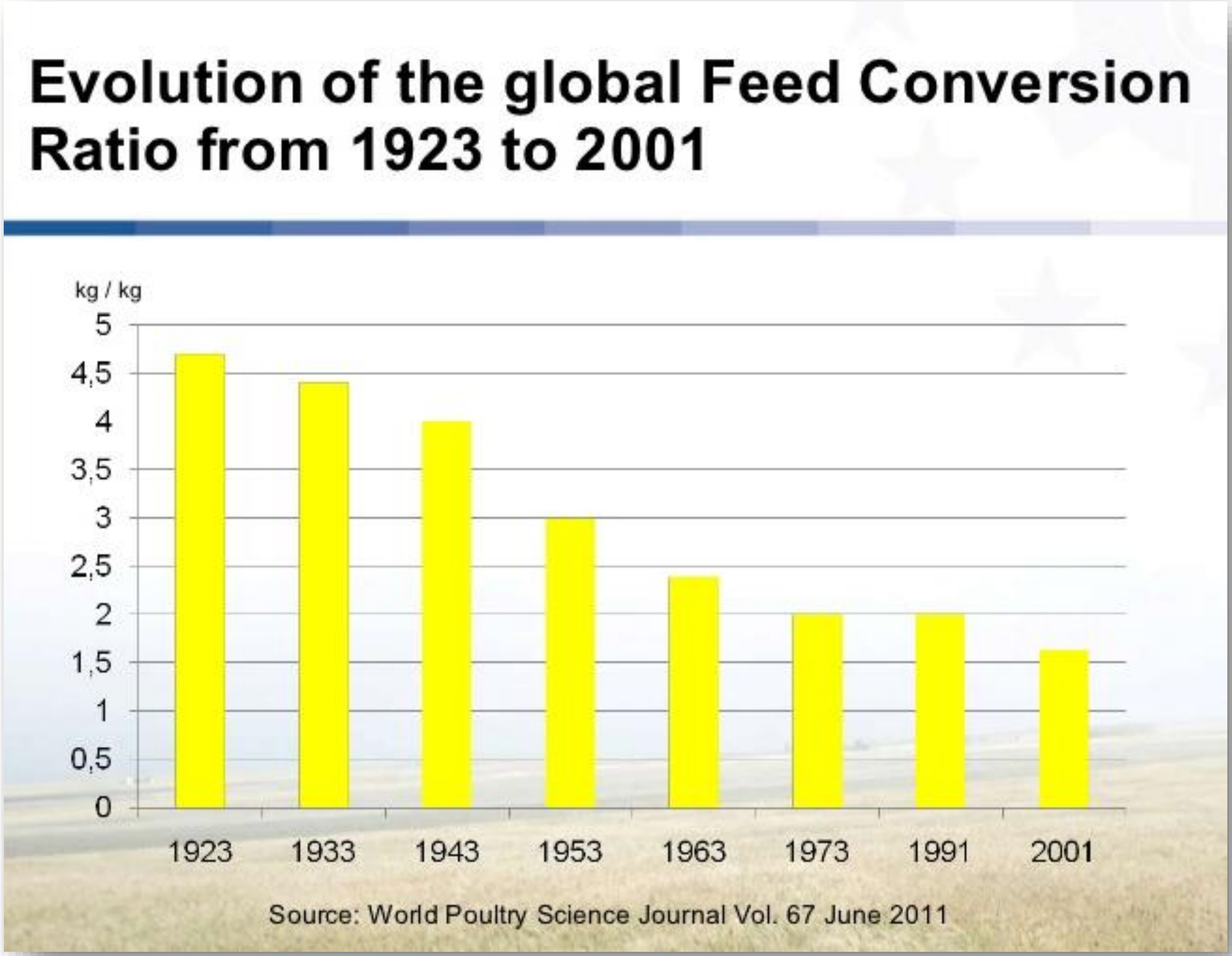
# Feed conversion ratios




Whole milk, bone-in carcase fresh weight or egg + shell

Wilkinson, 2011

# Evolution of feed conversion ratio in poultry

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# Feed efficiency

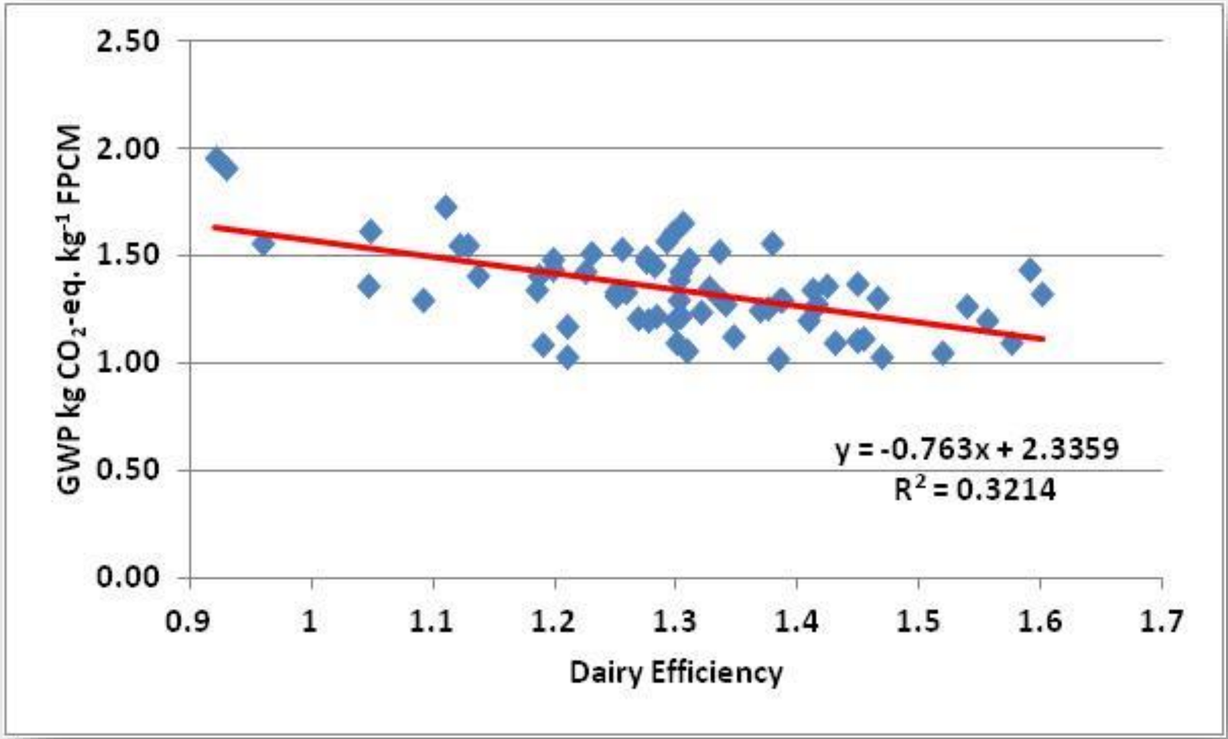
…genetics…

…welfare…

…health…

…feed quality…

…ration…




Guerci et al., 2013

The 10% improvement in feed efficiency leads to a 6.6-8.5% reduction in GHG emissions per kg of milk (Cederberg et al., 2009; White, 2016)

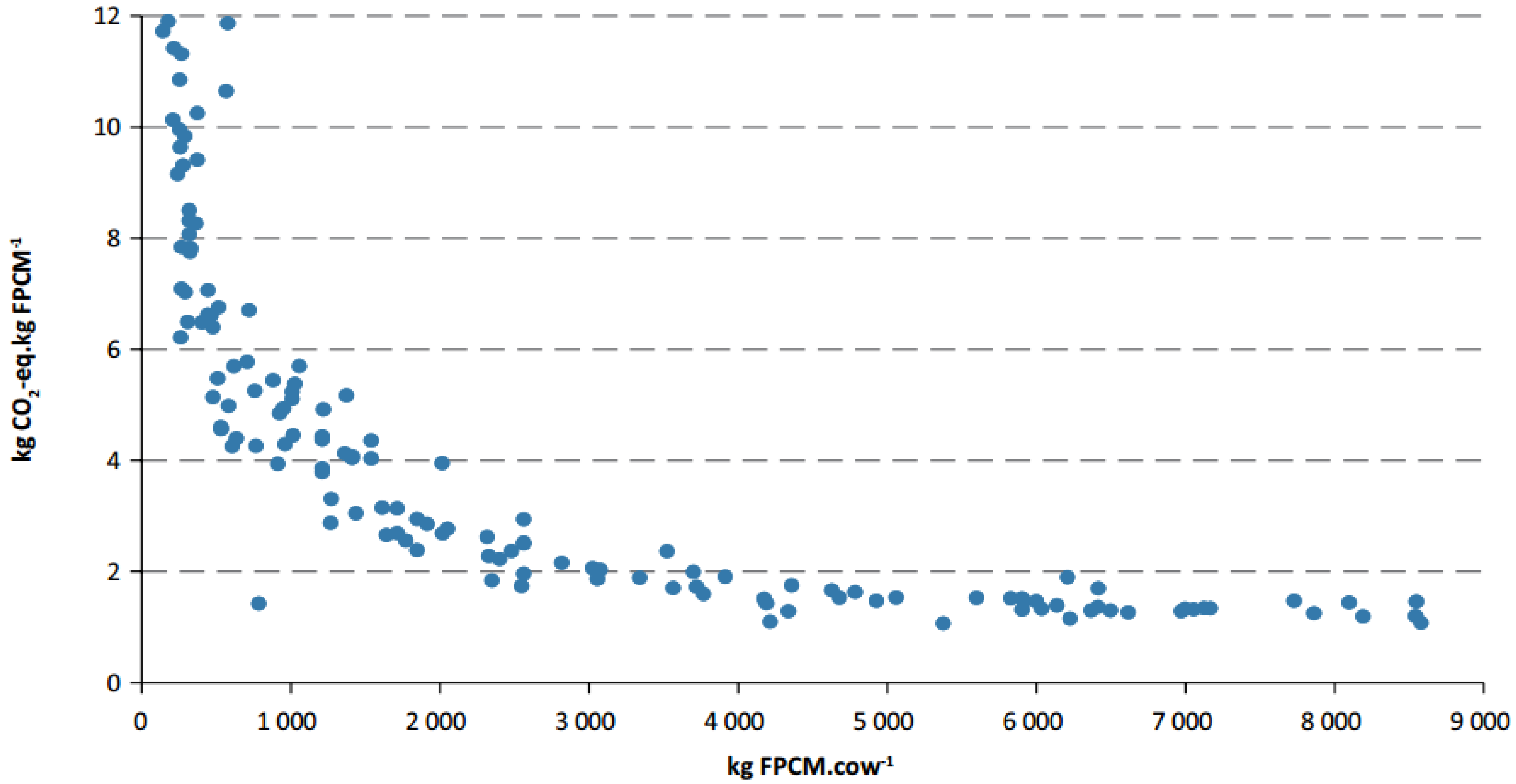
# Protein conversion ratios

| Food Item | # of data points | Protein Conversion Ratio (mean +-s.e.m.) |
|---|---|---|
| Beef | 40 | 20.0 +- 0.82 |
| Mutton and Goat | 63 | 14.5 +- 0.21 |
| Pork | 29 | 5.7 +- 0.63 |
| Poultry | 52 | 4.7 +- 0.24 |
| Eggs | 52 | 2.6 +- 0.29 |
| Milk | 37 | 3.9 +- 0.53 |
| Carp | 15 | 12 +- 0.72 |
| Catfish | 47 | 8.8 +- 0.04 |
| Char | 19 | 4.8 +- 1.43 |
| Cobia | 6 | 11.6 +- 0.11 |
| Cod | 19 | 4.8 +- 0.42 |
| Crayfish | 4 | 11.5 +- 0.09 |
| Halibut | 4 | 4.4 +- 0.08 |
| Salmon | 83 | 4.6 +- 0.2 |
| Sea-bass | 11 | 6.0 +- 0.29 |
| Seabream | 6 | 7.1 +- 1.67 |
| Shrimp | 91 | 18.3 +- 2.15 |
| Snapper | 15 | 16.5 +- 0.57 |
| Tilapia | 13 | 5.7 +- 0.51 |
| Trout | 35 | 4.1 +- 0.24 |
| Turbot | 10 | 14.6 +- 2.32 |

Number of studies and mean protein conversion ratios (feed protein used/edible animal protein produced) in examined terrestrial and aquatic livestock production systems with high use efficiencies.

Tilman and Clark, 2014

# Milk productivity and emission intensity




*Source:* Gerber *et al.*, 2011.

# GHG emissions per kg milk

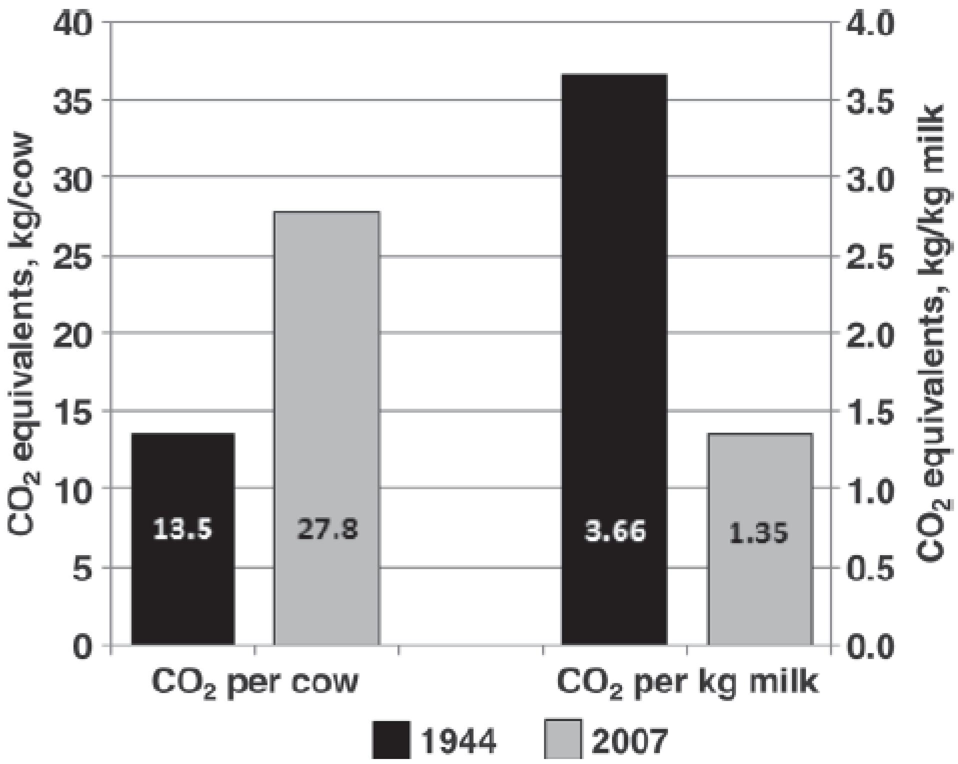
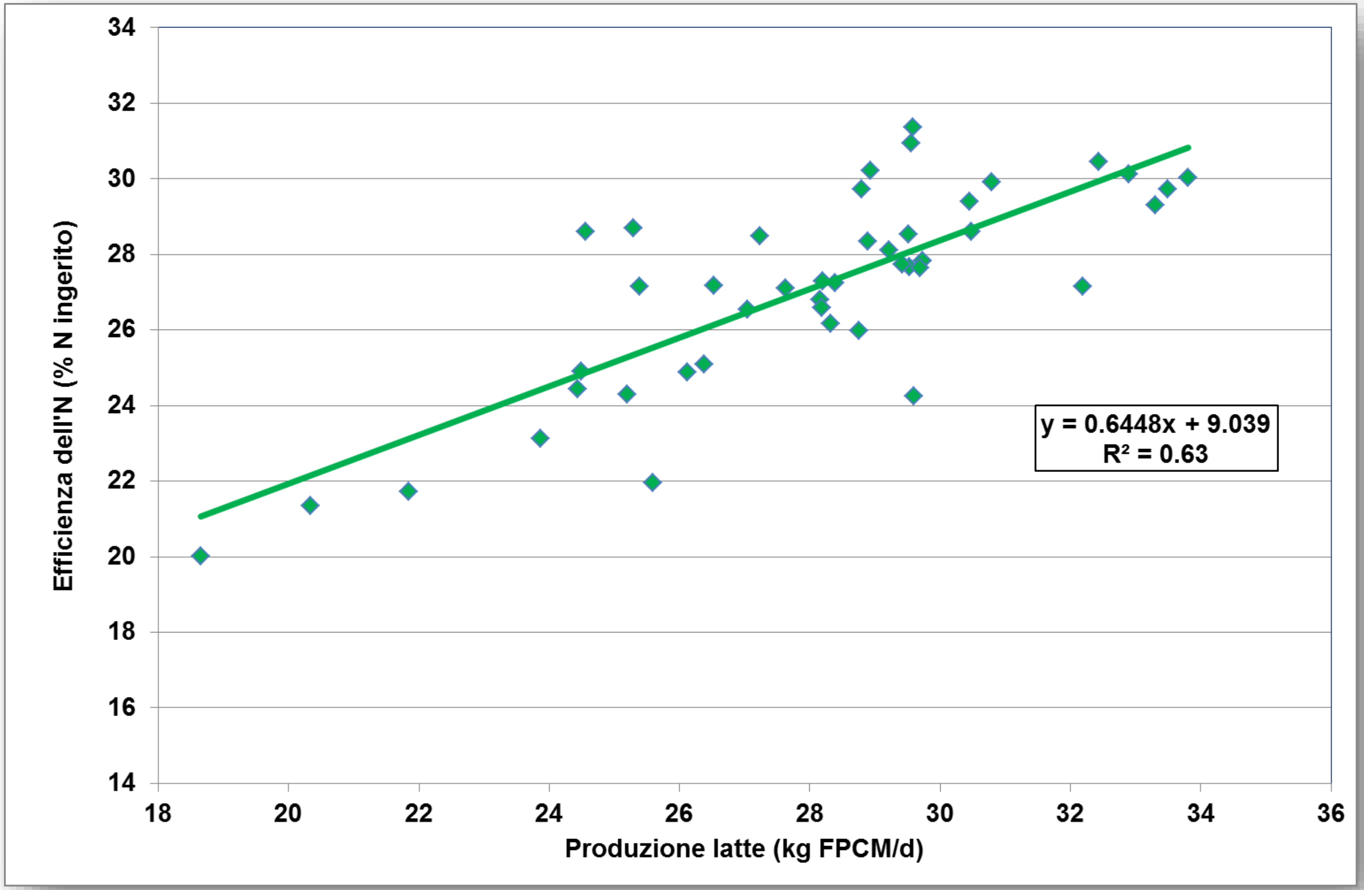



**Figure 3.** Carbon footprint per cow and per kilogram of milk for 1944 and 2007 US dairy production systems. The carbon footprint per kilogram of milk includes all sources of greenhouse gas emissions from milk production including animals, cropping, fertilizer, and manure.

In about 60 years, the emission of GHG per head has increased but per kg of milk produced has more than halved

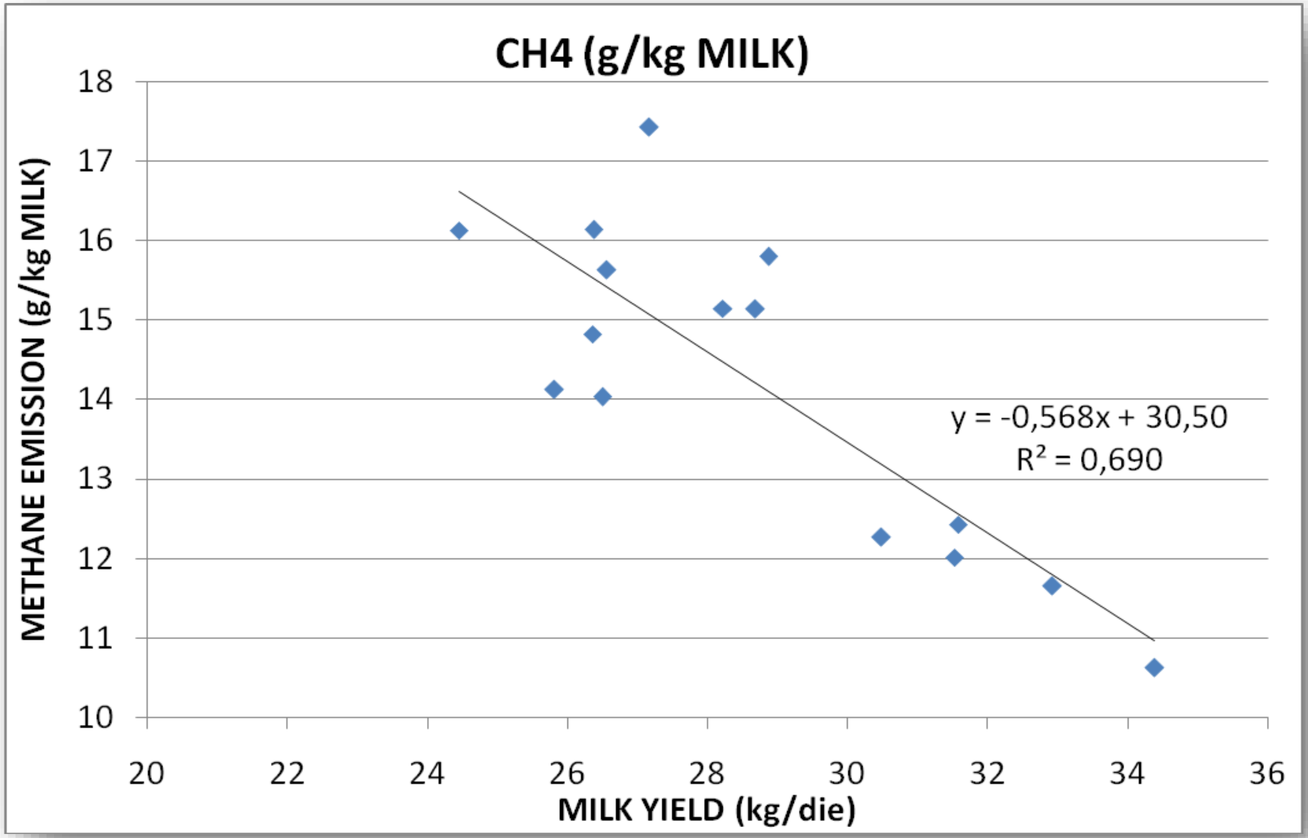
Capper et al., 2009

# Milk production and N use efficiency



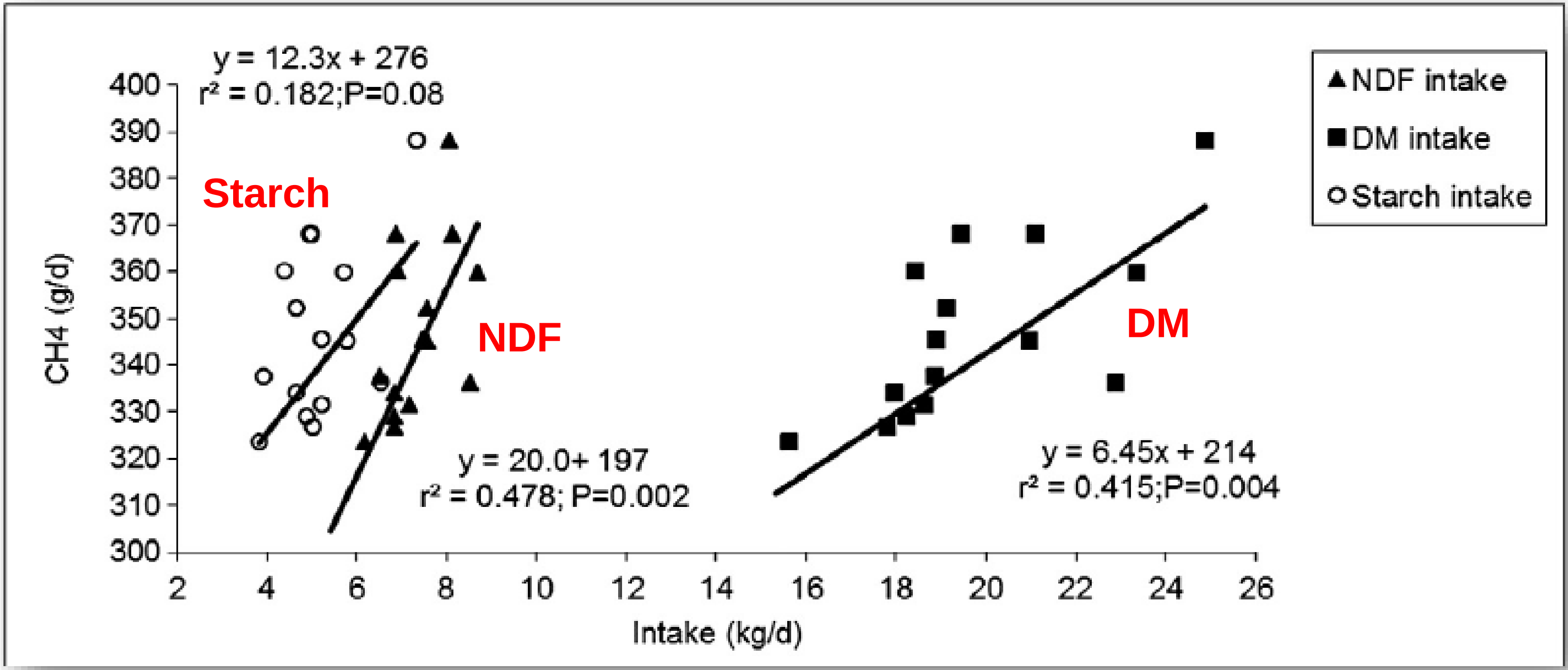

Guerci et al., 2013

# Methane emissions per kg milk




Pirondini et al., 2015

# Methane production and dry matter, starch and NDF intakes in lactating cows




Colombini *et al*. 2015

Higher $CH_4$ emission with NDF than with starch.

# Animal production systems

Three main systems:

- **Extensive** (usually small-scale, family farming)
- **Semi-intensive** (medium-scale)
- **Intensive** (large-scale, industrial farming)

# Animal production systems

## Extensive systems

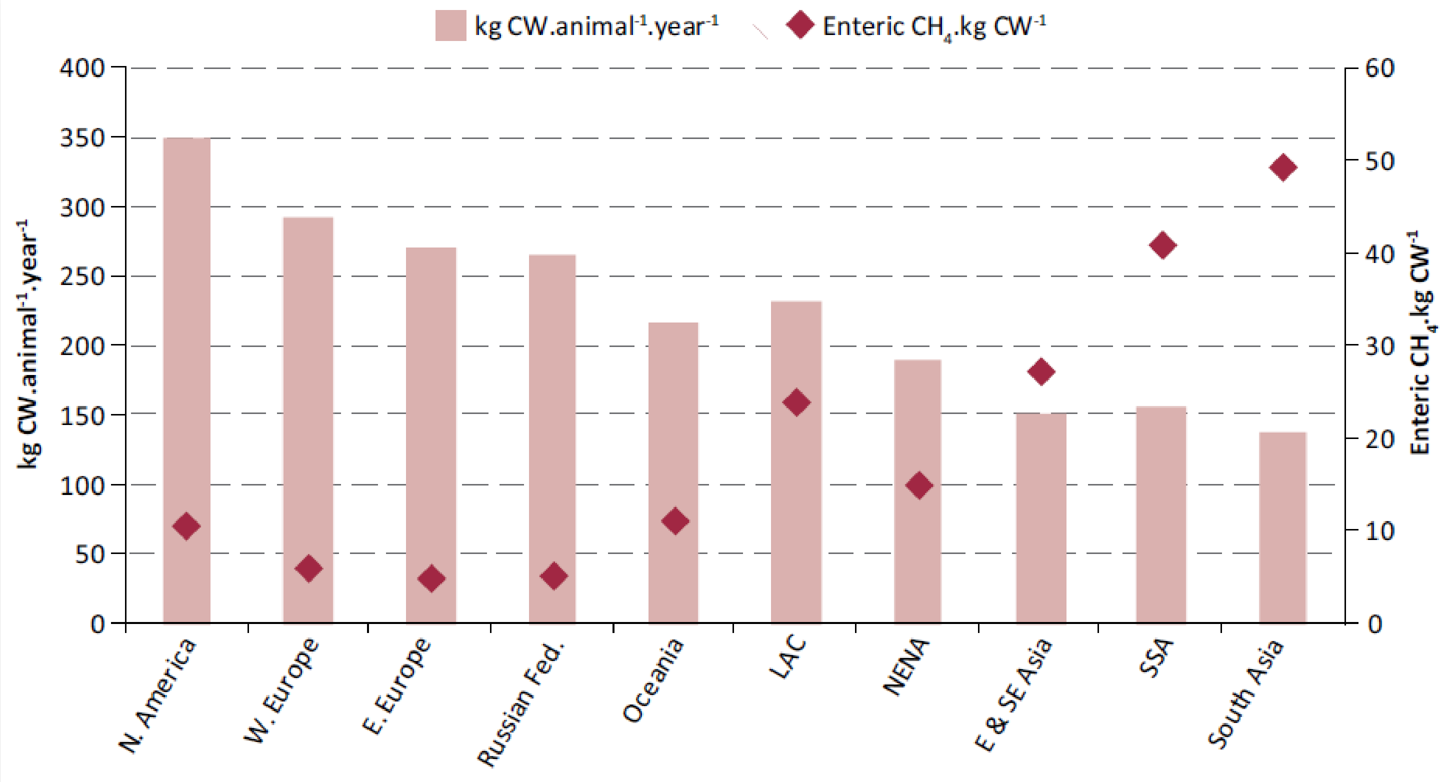
- Based on pasture, by-products
- Low input
- Low stocking density
- Low production level
- High feed conversion ratios
- Closed cycles
- High impacts per kg product

## Intensive systems

- Based on purchased concentrate feed
- High input
- High stocking density
- High production level
- Low feed conversion ratios
- Open cycles

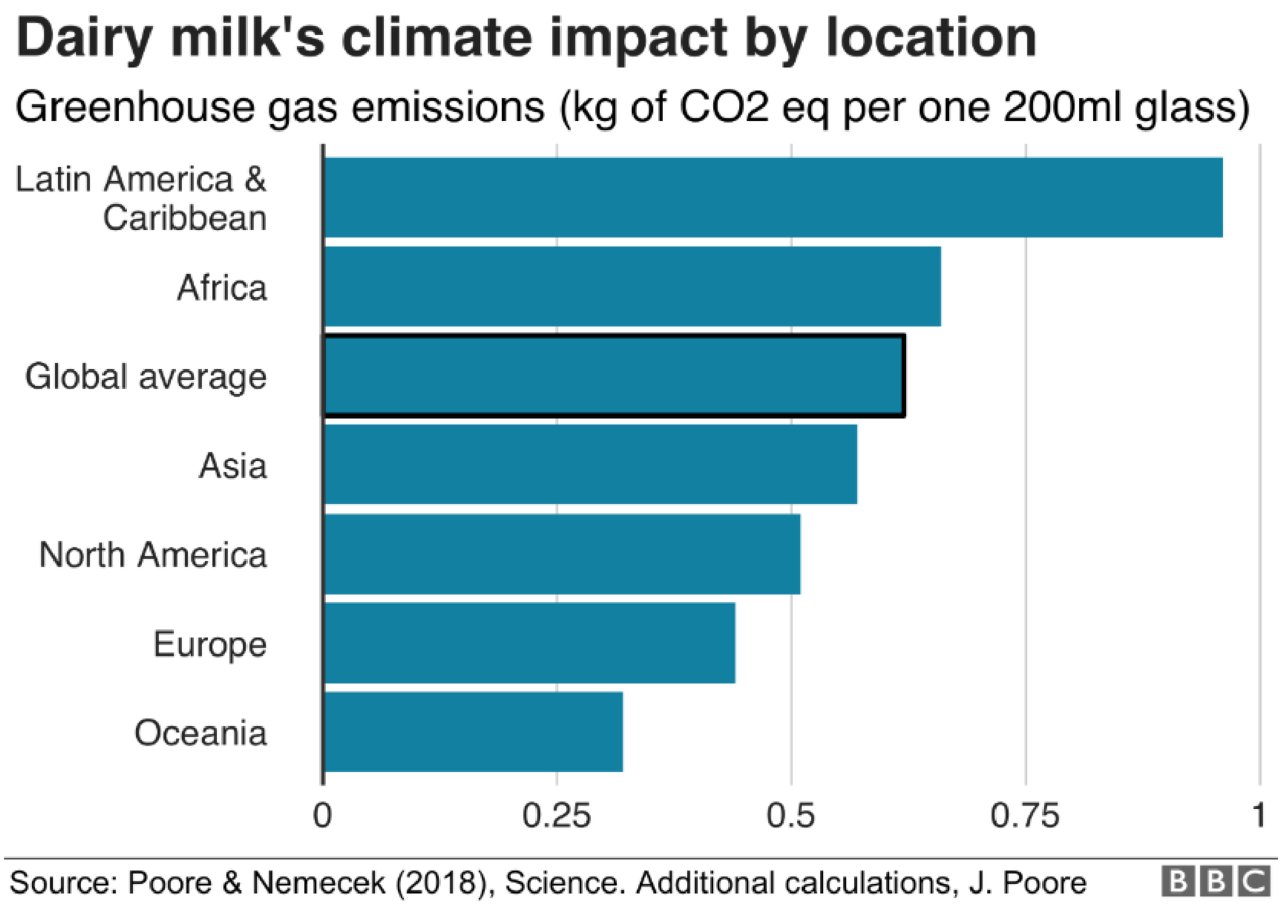
The majority of the world population depends on these intensive food supply systems

# Variability of GHG emissions per kg CW



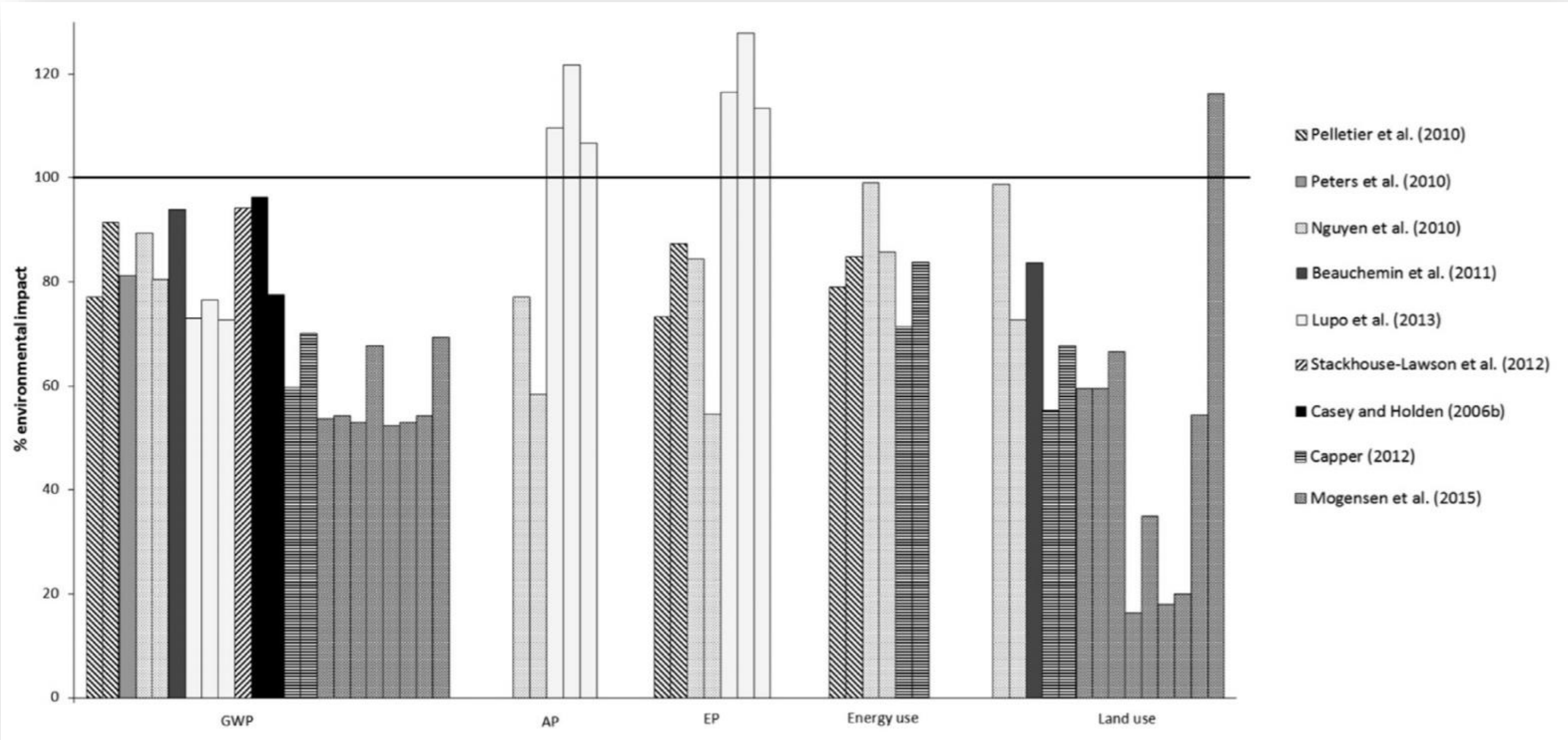

*Source:* GLEAM.

# Variability of GHG emissions per glass of milk




IPCC, 2014

# Environmental impacts per unit of product of concentrate-based relative to roughage-based beef production systems

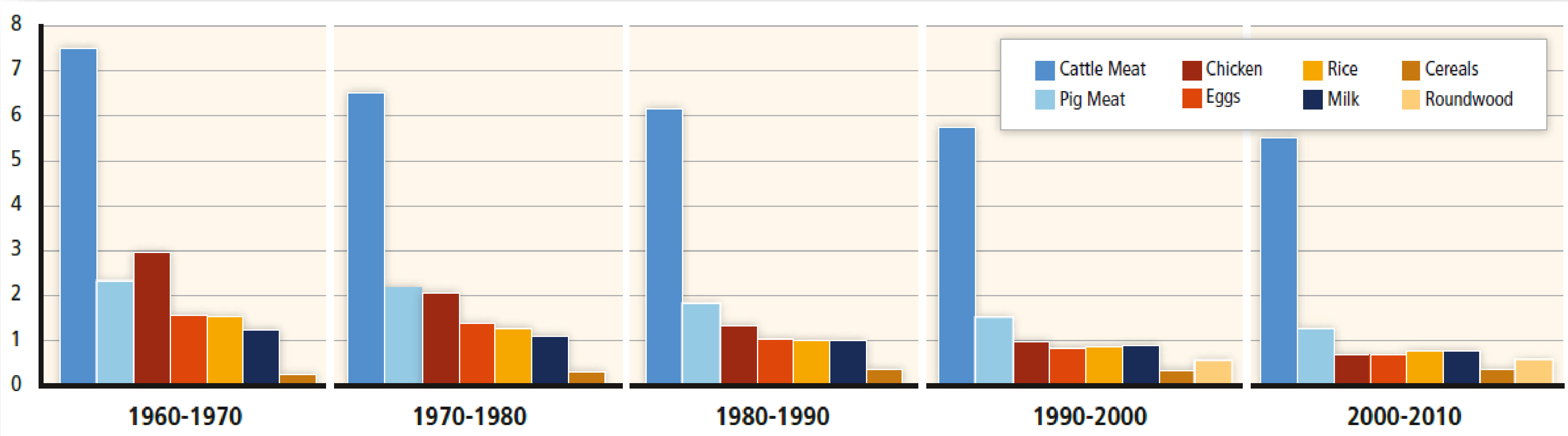



de Vries et al., 2015

GWP=global warming potential; AP=acidification potential; EP=eutrophication potential.

# GHG emissions intensities of selected agriculture, forestry and other land use commodities for decades 1960s – 2000s.

kg $CO_2$eq/kg or $m^3$ product




As agricultural and silvicultural efficiency have improved over recent decades, emissions intensities have declined.

Whilst emissions intensity has increased (1960s to 2000s) by 45% for cereals, emissions intensities have decreased by 38% for milk, 50% for rice, 45% for pig meat, 76% for chicken, and 57% for eggs.

IPCC 2014

# Farm efficiency

•The environmental impact of livestock production is related not only to feed efficiency but also to reproductive efficiency, management of young animals, diseases, mortality

•In addition, a livestock farm is a complex system consisting of a set of components that interact with each other: soil, crops, animals, wastewater, human component

•On each of these aspects and in the interaction between them, we can work to improve efficiency, reduce waste, reuse waste

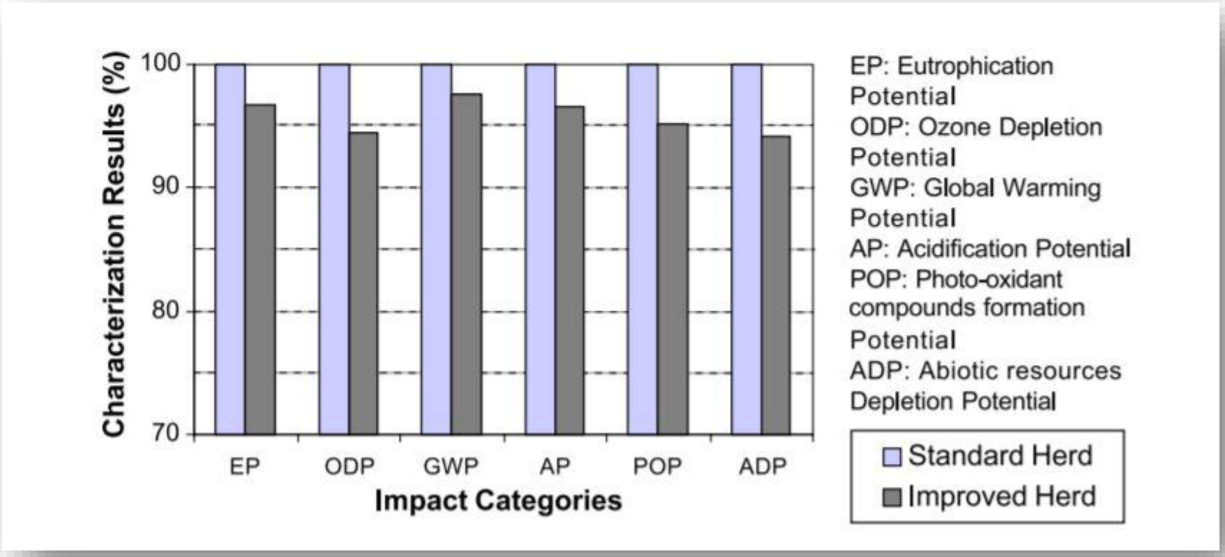
# Welfare, health, fertility, longevity

Poor welfare conditions, diseases, poor fertility and reduced longevity cause an increase in the environmental impact of animal production for:

- lower feed efficiency and production decrease/waste
- need for more replacement animals
- increase in unproductive days
- therapies

# Welfare, health, fertility, longevity

The reduction of the incidence of clinical mastitis from 25 to 18% and of subclinical mastitis from 33 to 15% allows to reduce the emission of GHG for the production of milk by 2,5% (better feed efficiency, reduction of milk losses , reduction of discarded milk)




Hospido and Sonesson, 2005

# Welfare, health, fertility, longevity

The improvement of fertility can lead to a reduction of the methane and ammonia emissions of the herds estimated in respectively 24 and 17% Garnsworthy, 2004

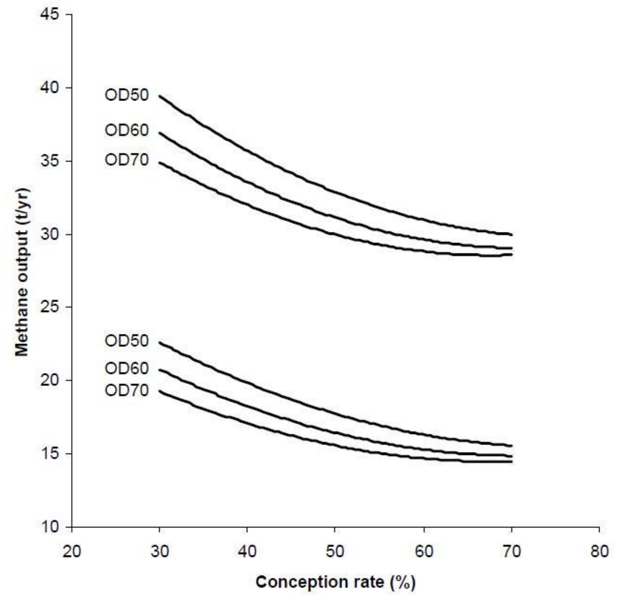



Fig. 5. Annual methane output per herd in dairy herds with varying conception rate and oestrous detection rates of 50, 60 or 70% with a milk quota of one million litres per year and a mean annual milk yield of 6000 or 9000 l per cow.

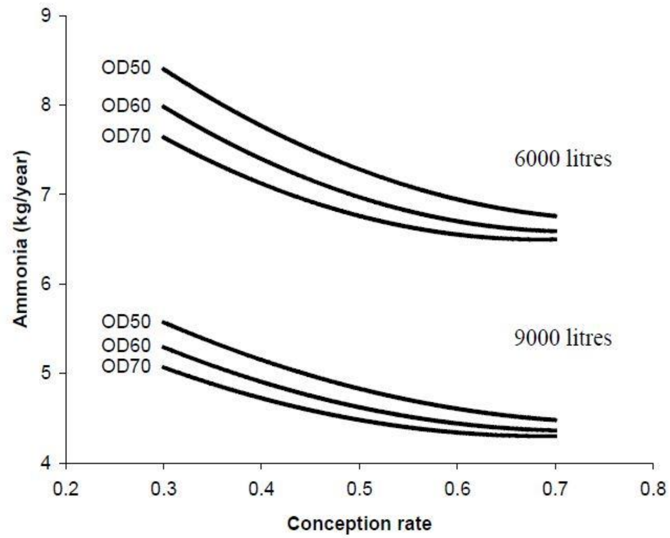



Fig. 7. Annual ammonia output per herd in dairy herds with varying conception rate and oestrous detection rates of 50, 60 or 70%, with a milk quota of one million litres per year and a mean annual milk yield of 6000 or 9000 l per cow.

# Fibrous feed and by-products

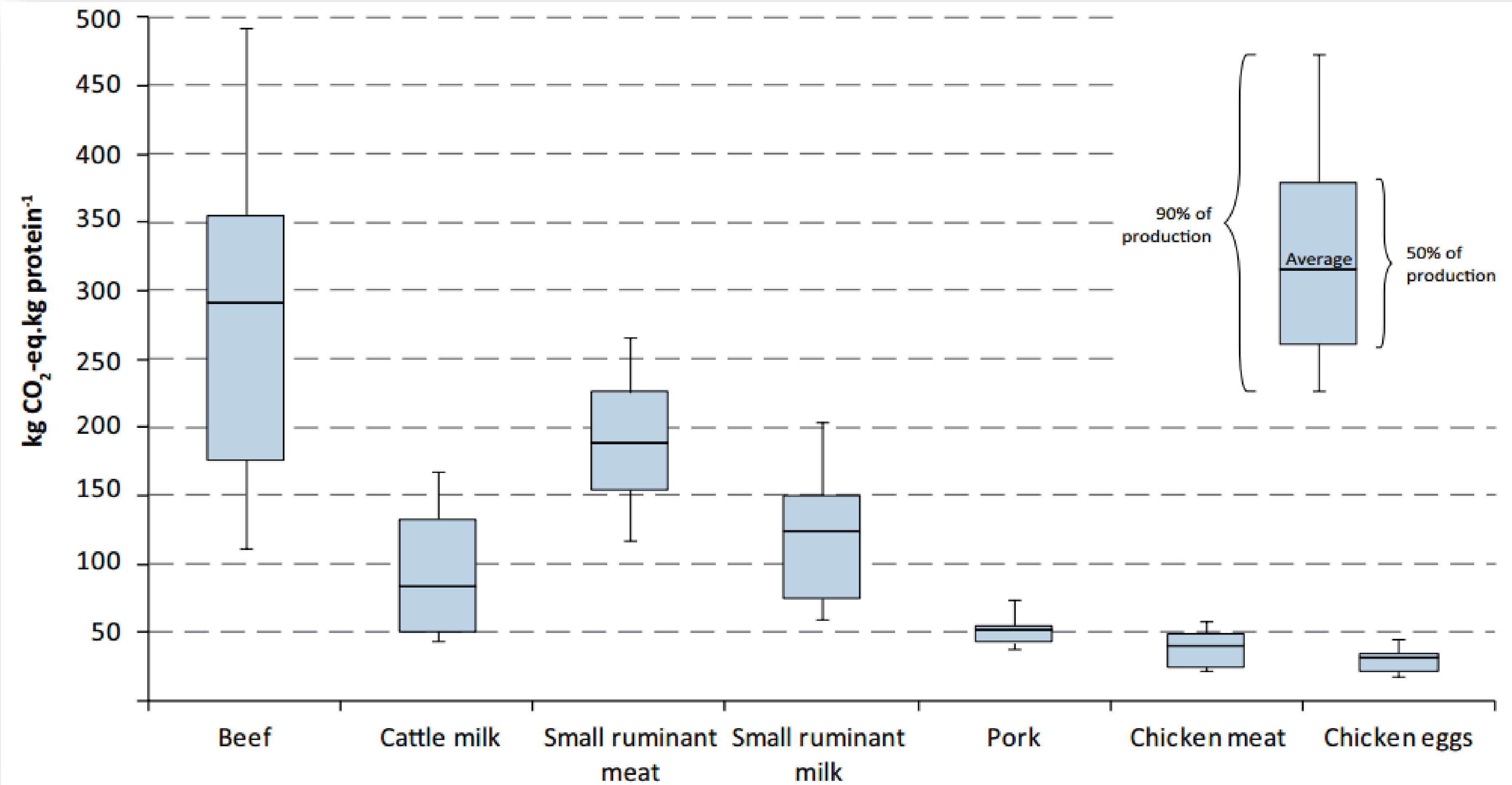
Ruminant animals can use feed produced on land less or not suitable for the cultivation of vegetable products for human consumption, such as natural pastures, and they can also be fed with by-products.

Livestock annually converts over 432 billion kg of non-human edible by-products/fibrous feed to edible food for humans, pet food and industrial products, in addition to 4 billion kg of N that can be used as fertilizer (White & Hall, 2017)

# Forage systems for ruminant production

- ✓ Nowadays there is more attention to permanent or semipermanent meadows for their ability to improve C sink in the soil
- ✓ Replanting grasses in lands previously sown with annual crops can result in a significant increase in soil C, and in some cases the soil C gain more than offset all the GHG emissions from the farming system (*Guyader et al.*, *2016*).

# GHG emissions per kg of protein from different sources




Gerber et al., 2013

# GHG emission per different functional units

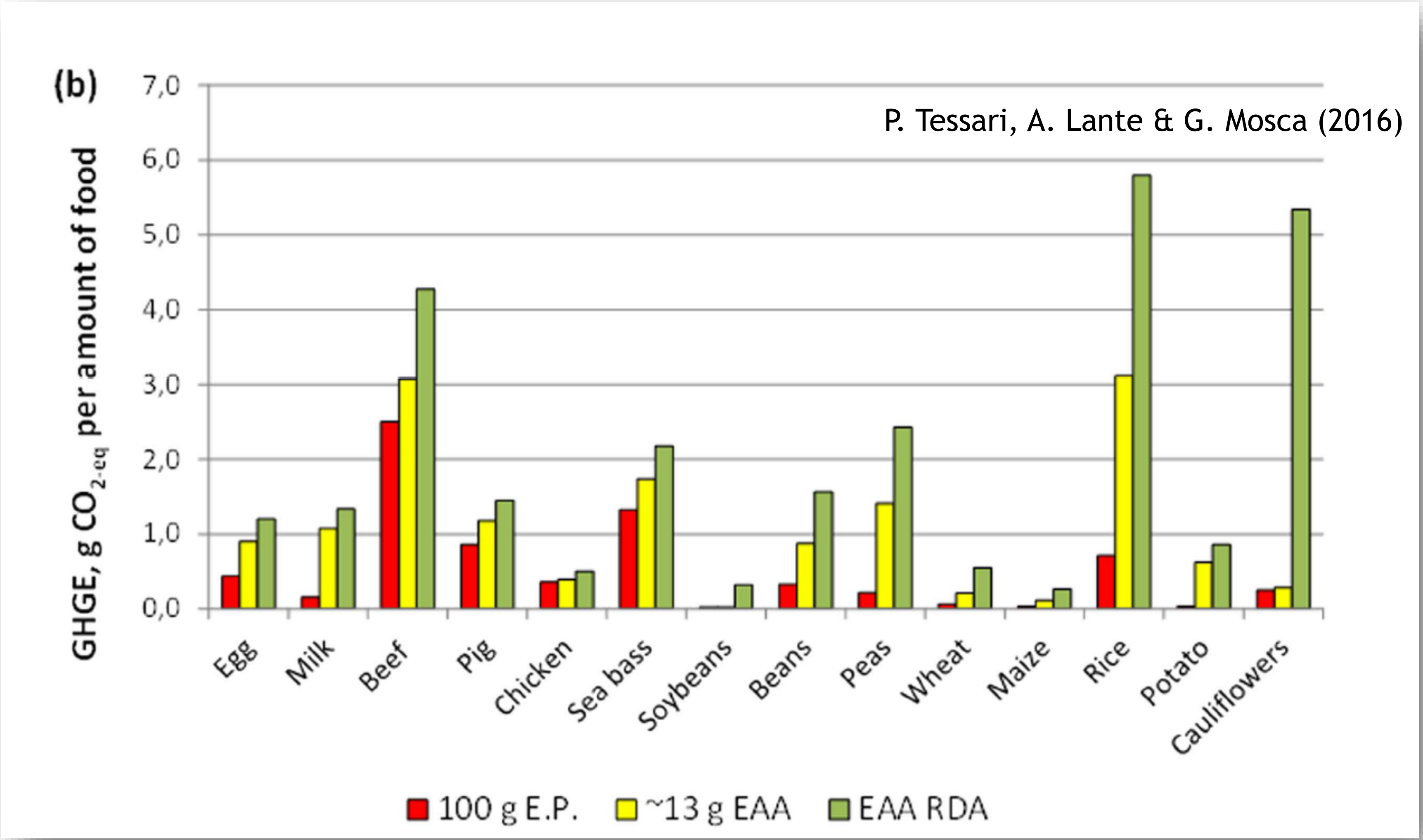
*Table 2: Greenhouse gas emissions (g $CO_2$-eq) of six protein rich food products measured with five different functional units: 100g, portion, 100kcal, g protein, and the Nutrient Density Unit.*

| Product | portion size | NDU | Greenhouse gas emissions (g $CO_2$-eq) | | | | |
|---|---|---|---|---|---|---|---|
| | gram | | per 100g | per portion | per 100kcal | per 10g protein | per NDU |
| Pulses, brown beans, canned | 75 | 2.87 | 250 | 188 | 225 | 352 | 87 |
| Milk, semi-skimmed | 250 | 0.99 | 108 | 270 | 235 | 318 | 110 |
| Nuts, mixed, salted | 25 | 1.52 | 229 | 57 | 36 | 102 | 150 |
| Egg, chicken, boiled | 50 | 1.48 | 282 | 141 | 207 | 229 | 190 |
| Salmon, aquaculture, prepared | 130 | 2.31 | 485 | 631 | 220 | 192 | 210 |
| Pork, raw, 5-14% fat | 100 | 2.05 | 709 | 709 | 449 | 336 | 345 |

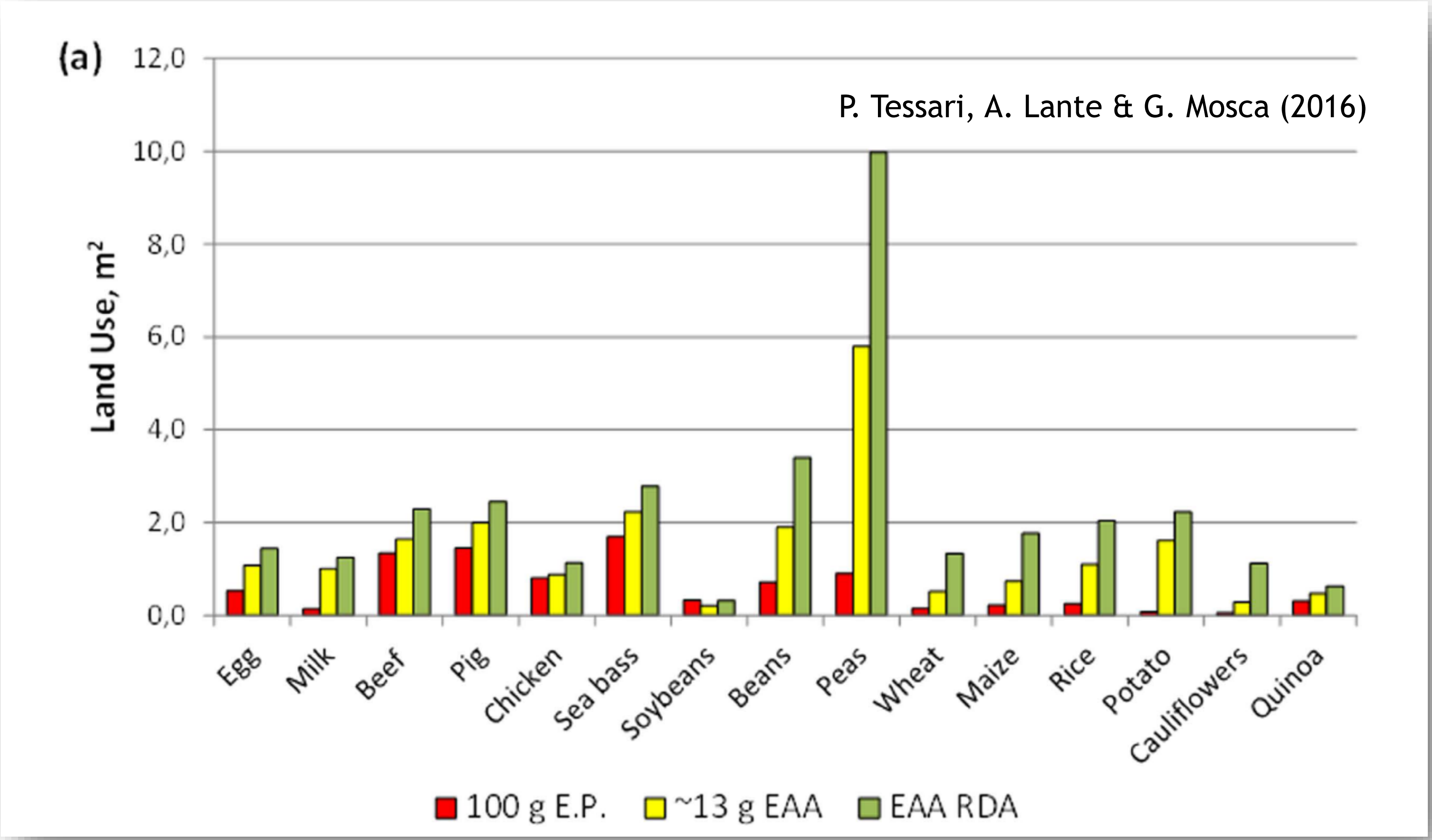
NDU: essential fatty acids, protein, fibre

Van Dooren, 2016

# GHG emissions per 100 g Edible Protein, 13 g EAA, EAA RDA



# Land use per 100 g EP, 13 g EAA, EAA RDA



# Single impact score per 300 g digestible protein from different products

Smetana et al., 2015

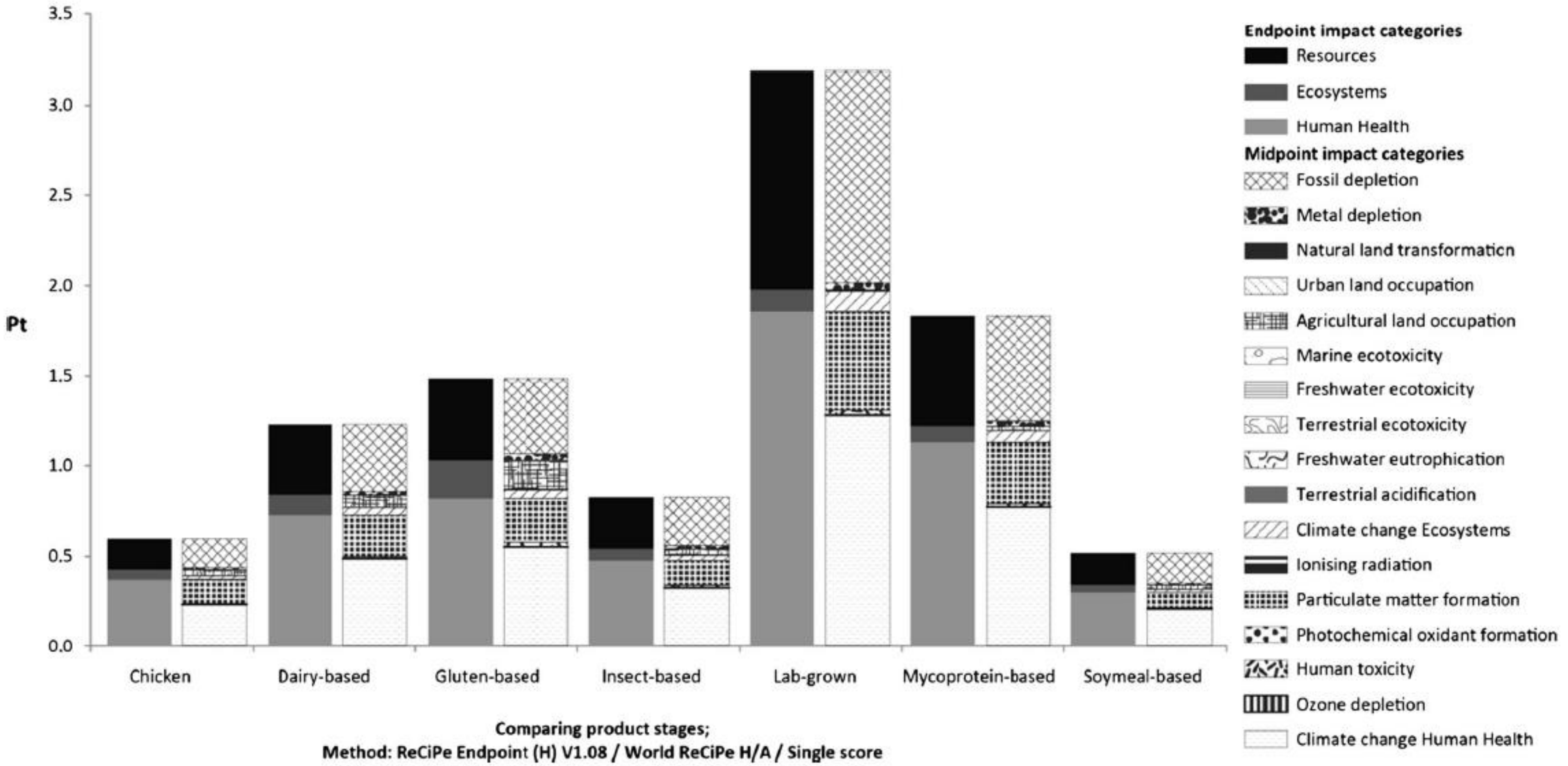



**Fig. 7** Single-score alternative FU (0.3 kg of digested proteins) product comparison (from cradle to plate)

# GHG emissions from different protein rich products

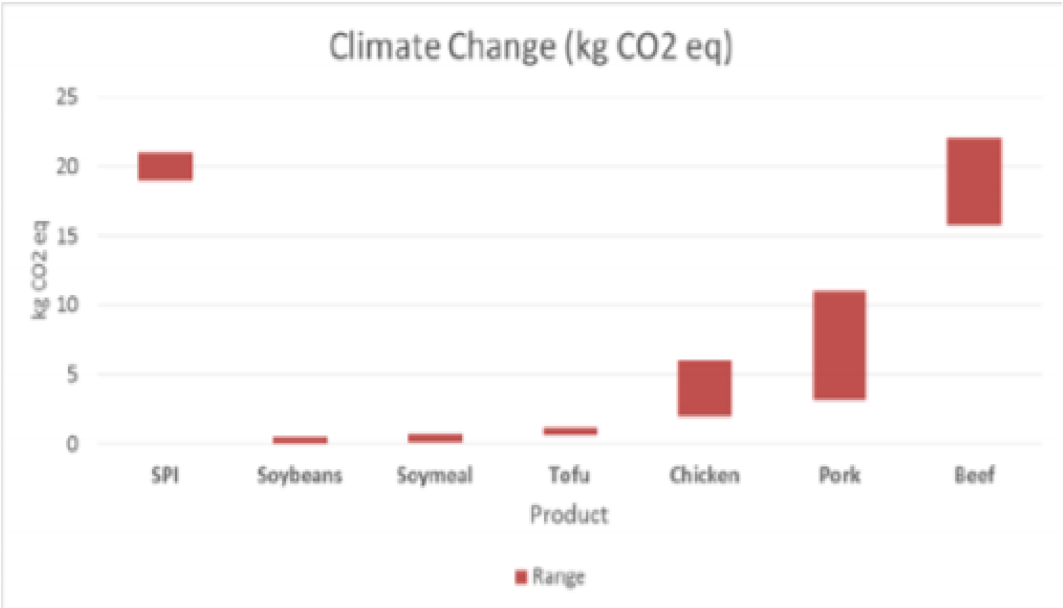



Figure 4. Floating column chart showing approximate ranges for climate change potential of 1 kg each of a variety of comparison products.

soy protein isolate (SPI)

Berardi et al., 2015

# Better to ban animal husbandry?

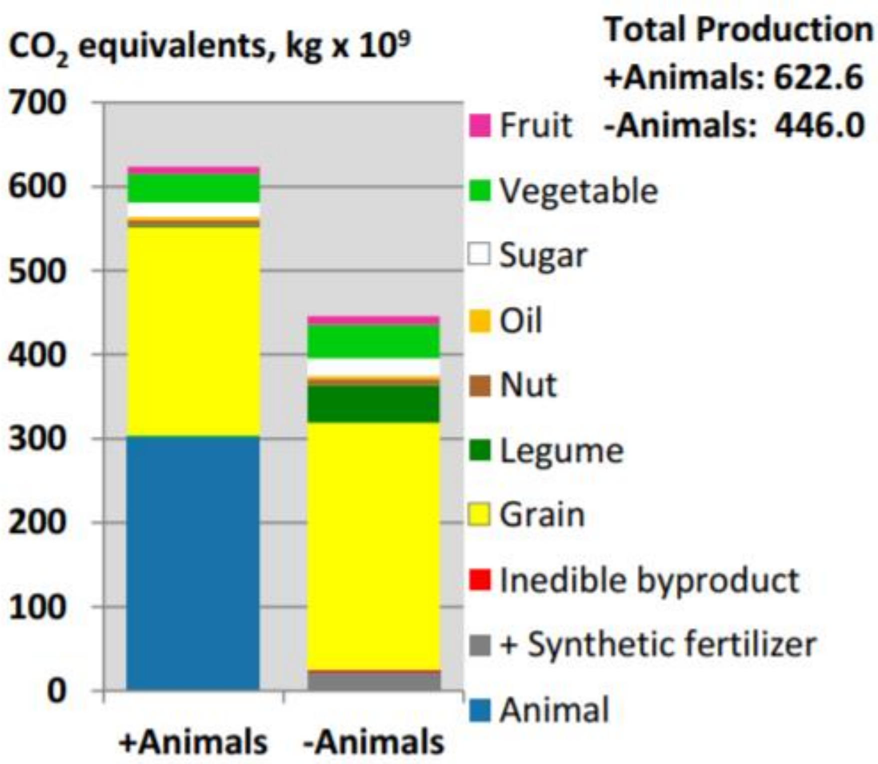



**Fig. 5.** GHG emissions associated with food production in a system representative of the current United States and a modeled system in which animal-derived food inputs are eliminated.

White & Hall, 2017

The GHG produced by the US agricultural system would decrease by 28% with the elimination of animal husbandry and not by 49% (estimated impact of animal husbandry) due to the need to synthesize fertilizers to replace animal fertilizers, to dispose of inedible by-products for humans previously used as animal feed and to produce additional crops on land previously used by animals. In total, the elimination of animal husbandry would only reduce total U.S. GHG emissions by 2.6 percentage units

# Conclusions

- ✓ Food of animal origin are important for human diet
- ✓ A large part of ice-free land is not suitable for arable crops to produce feed for humans but it can be used for pastures
- ✓ Forages and fibrous feed can be advantageously used only by ruminants to produce high biological value proteins
- ✓ Extensive livestock production systems have higher environmental impact per kg of product than intensive ones due to low efficiency.
- ✓ Intensive systems are essential for food supply. They can cause local environmental impacts (e.g. eutrophication) and they can negatively affect soil carbon stock, locally or in other areas (e.g. Brazil)
- ✓ Without intensive farming much more soil should be used, to the detriment of virgin areas, and the average environmental cost per kg product would increase

# Sustainable intensification

- Agricultural systems capable of increasing unit production without negative effects on the environment and without cultivating other land (Royal Society, 2009)
- Expression used for the first time in the late 90s
- It is not just an increase in production per unit of soil but above all an increase in the efficiency of use of the production factors

# Ask a question