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The Mitigation of Climate Change Through the Reduction of GHGs Emissions Coming From Livestock

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Summary

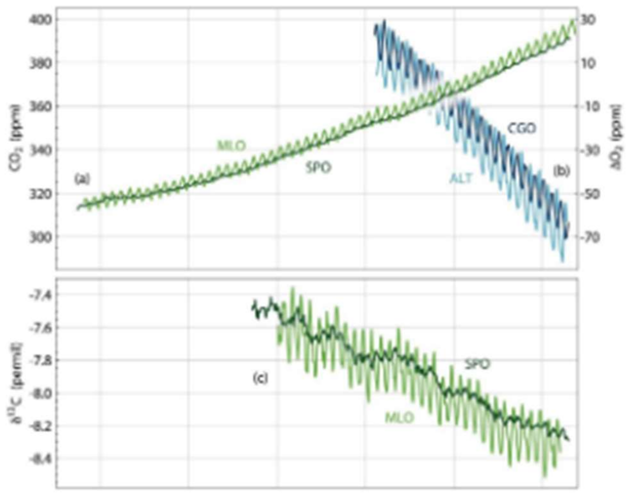
Introduction

By climate change we mean a long-term change in the average weather patterns that define the Earth's climates both regionally and globally. The main phenomena are the increases in land and ocean temperatures, ice loss, increase in the frequency and severity of extreme weather conditions, such as hurricanes, heatwaves, wildfires, floods and precipitations and vegetation changes[1]. An important milestone in climate change science can be found in the World Meteorological Organization (WMO) conference held in Geneva in 1950[2]. During that conference, a gathering of scientists, divided into four working groups, analysed climate data in order to shed some light on various climate topics, the studies already held on the matter and its variability. The meeting led to the creation of the World Climate Programme and the World Climate Research Programme. Furthermore, it led to the creation of the IPCC (Intergovernmental Panel on Climate Change) in 1988. Nevertheless, the subject has been hardly ever taken into serious consideration at governmental level throughout the years, leading to the current situation. Scientists insist in confirming that the time we have left to stop climate change to cause irreparable damage is between 18 months and 12 years[3]. Either way, time is running out and action needs to be taken.

Having said that, why is it so urgent of a matter and why governments are not acting as needed? One of the reasons as to why it has never been taken seriously is because there has always been uncertainty on who or what caused climate change. Is it something caused by humans (human drivers) or by nature (nature climate drivers)? There's no doubt, that some of the changes are caused by nature itself, as a normal process of cooling and heating, but most of them are caused by the human hand. For years, there has been some scepticism over this possibility, and even now there are some politicians who guarantee that there's still not enough scientific proof to state that human actions have any effect on the climate. This belief has, however, been dismissed by various studies which show how human activities are the main cause for it (i.e. transport, farming, etc.). How to prove that human actions are the main cause of climate change?

[1] Nasa.gov, https://climate.nasa.gov/resources/global-warming-vs-climate-change/
[2] World Meteorological Organization, https://public.wmo.int/en/about-us/who-we-are
[3] BBC.com, https://www.bbc.com/news/science-environment-48964736

To prove human responsibility, first it needs to be understood how climate change is monitored. The phenomenon is defined through CO2 emissions and its source. Each emission contains a certain amount of atoms of carbon, which allow to trace the origin of the emission as they are significantly higher in fossil fuels than natural factors. This CO2 also contains particles that absorb the sunlight and make the temperature rise. To further prove human involvement, the IPCC confirmed that an increase in global warming has been witnessed since the mid-20th century, which coincide with the industrial revolution. This conclusion was reached after testing with sophisticated computers the changes in the climate caused by natural climate drivers and the changes that could be traced back to human drivers, such as the burning of fossil fuels and the forest clearing. After the tests it was clear how anthropogenic drivers are the main contributor in climate change as they had a way bigger impact on the environment[4]. As it can be seen in graph 1 (below), even if the amount of total CO2 emitted is increasing in the years, the amount emitted by natural drivers has decreased, further proving that anthropogenic drivers have a bigger impact.



Graph 1. Direct Evidence of Fossil Fuels Derived CO2 in the Atmosphere. Source: IPCC AR5

The organization created to prove the scientific relevance of climate change is the IPCC (Intergovernmental Panel on Climate Change), which has been founded in 1988. In

[4] Union of Concerned Scientists, https://www.ucsusa.org/resources/are-humans-major-cause-global-warming

particular it shows its discoveries and analysis through assessment reports, which are a summary of other scientific papers that are reviewed and put together to help analyse the drivers of climate change and possible solutions that can be applied to mitigate and adapt to it. The main goal of this institution is to offer an unbiased opinion by involving experts from various countries and different backgrounds to increase the relevance of scientific agreement.

As briefly explained before, this phenomenon is usually measured through the consideration of greenhouse gas emissions, specifically carbon dioxide, nitrogen and methane, all of which are transformed into CO2e (carbon dioxide equivalents) to keep the measurement easier to analyse and allow a comparison between the different sources of GHGs (greenhouse gases). A clarification needs to be made however, as not all the gases have the same impact. Regardless of the fact that Carbon Dioxide is the gas that is the most mentioned and the one used to measure, Methane as 86 times more warming capacity than CO2 in a twenty-year time span according to the Intergovernmental Panel on Climate Change[5]. A gas that is also 21 times better at trapping heat than CO2 in the atmosphere[6].

What does climate change translate into? The main phenomenon caused by climate change is global warming. This is the main concern, mostly because it affects everyone and it is easy to understand, furthermore most of all the other phenomena are caused by it. What is exactly doing global warming to the earth? The arctic sea ice is melting with an average of 3.2% decrease in the area covered by sea per decade[7]. This happened because the average temperature in winter has been rising, reaching its peak in 2016. This means that also the ocean heat is increasing, damaging marine ecosystems and coral reefs, consequently the decrease in areas covered by ice, reduces the amount of sunlight reflected back into the atmosphere (the ice is white, and its surface is able to reflect the sun rays, keeping the earth at a cooler temperature, while the ocean its dark and absorbs heat, making the planet warmer). Besides the heating of the ocean, its level

[5] Scientificamerican.com, https://www.scientificamerican.com/article/how-bad-of-a-greenhouse-gas-is-methane/

[6] IBTimes.com, https://www.ibtimes.com/cow-farts-have-larger-greenhouse-gas-impact-previously-thought-methane-pushes-climate-1487502

[7] National Snow and Ice Data Center, http://nsidc.org/arcticseaicenews/tag/arctic-sea-ice/

is rising too, as warm water expands, if compared to cold water and as glaciers and ice caps are melting, leading to the formation of permanently flooded areas in the near future. Moreover, the air above the ocean is heating up, causing an excess of vapor, which is leading to an increase in hurricanes and other natural catastrophes. Finally, temperature in the lower atmosphere is increasing, mainly due to fossil fuels that create a cap and block the sun from being reflected into the atmosphere[8].

Are all countries producing the same amount of CO2? Are all countries responsible at the same level? There are some factors that need to be taken into consideration when analysis the total emissions of the different countries, as the analysis takes a different take and shows the differences between countries. These factors are the following: some countries have a denser population than others (meaning more people that inevitably contributes to the production of GHGs) and some are fast-developing countries (meaning countries that still don't have access to the newer resources that have a smaller impact on the planet). Having said that, if these factors are not taken into consideration, the results show that China is the country with the highest level of CO2 emissions, while when measured the emissions per capita, the figures change. Emissions per capita show that the USA is the main polluter, reaching 19.8 tonnes per person, compared to the 4.6 tonnes of the Chinese. This measurement also shows the greater responsibility of developed countries, rather than the developing ones[9].

In the following chapters it will be disclosed what is the human activity that affects climate change the most, why it is so damaging to the planet and the possible solutions that could be applied to limit the increasing damages caused by this phenomenon.

[8] Union of Concerned Scientists, https://www.ucsusa.org/resources/ten-signs-global-warming

[9] Theguardian.com, https://www.theguardian.com/environment/datablog/2009/sep/02/carbon-emissions-per-person-capita

Chapter I: An insight on livestock's impact on the environment

Chapter number one will discuss how livestock became one of the main causes of climate change, not only directly, with emissions coming from the animal itself, but also indirectly, through all the activities related to its production and maintenance. Firstly, an insight on the two main ways of production is necessary, intensive production and extensive production, and they will be presented with their pros and cons. Afterwards, the elements affecting both consumption and production of livestock will be explained, in particular how anthropogenic factors are influencing quantities and the locations of major consumers. From an increase in the average income per capita to the development of new technologies to changes in cultural dynamics. Finally, the chapter will delve into what are the indirect factors that can be traced back to livestock and which of the greenhouse gases are related to the animal foodstuff production. To understand the analysis present in the following chapter, some observations will be made, specifically, in how most of the researches mentioned will address different scenarios with different results, and how it is important to maintain a critical eye and remember the limitations of these models.

What is livestock and why does it have an impact on the climate? Livestock means a group of domesticated animals raised to produce labour and commodities, such as food and textiles[10]. When considering only domesticated animals raised to become livestock, they represent 40 percent of the agricultural GDP (Steinfeld et al., 2007). Furthermore, the demand for its products is also increasing rapidly, as they are becoming accessible even to the poorest countries through a rise in incomes, an increase in the population and urbanization, this increase is so relevant that it is forecasted that by 2050 the demand of meat products will more than double. One of the main consequences of this high demand is how it influences the land used to grow the feed crops necessary to feed the animals, which reaches 1/3 of the land surface of the planet (Steinfeld et al., 2006). Given that the amount of land occupied for this reason is so vast, it is quite straightforward to understand why it has such a big impact on climate change. Livestock is responsible for land-based pollution by emitting nutrients, pathogens and drug residues in rivers and the sea. It also produces various greenhouse gases and due to the

[10] Britannica.com, https://www.britannica.com/animal/livestock

high demand of feed crop and the space necessary to grow it, it is also responsible for changing whole natural habitats, that are swept off to give space to cropping. Moreover, given the limited space, cropping is also approaching an intensive system which only increases the damages to the earth.

Which elements are included in the calculation of the livestock's emissions? When considering livestock in the calculation of emissions, it doesn't only mean the animal itself, it also includes all the fertilizers used, the land transformed to grow their food, the water used both during the farming and the production of its products. It also takes into consideration all the industrial process behind its maintenance and management. Furthermore, it involves a big amount of resources and the diversity of production, management, and locations (from intensive to extensive, from the areas it is practised in and its diverse production) is something that highly affects the other sectors too. As an example, if water is taken into account, livestock is responsible for the 70 percent of fresh water used (Steinfeld et al., 2006). Given the quantity of elements to keep into consideration when considering livestock as a main factor for climate change, this naturally generates a debate over how much of it is actually polluting and how precise the percentages are. However, as livestock does require and exploit, as mentioned before, a significant amount of resources it must still be considered as one of the major contributors of GHGs emissions even in the best-case scenario.

1.1 Types of production

Before venturing into the explanation on how and in what way livestock influences climate change, some clarifications need to be done. Extensive form of production has limited use of external inputs, and it is defined as depending on low-cost and locally available feed inputs, while the intensive approach mainly bases itself on marketable high-cost feed items. The high increase in livestock production everywhere in the world can be explained with the term industrialization, as thanks to the development of machines and techniques of breeding, the natural constraints of the earth are being deceived and the production of animal products has become easier as it is growing. The industrialization translates also in the tradability of the resources available across the globe, meaning that natural resources and environmental impact are also transferred.

1.1.1 Extensive form of livestock production

Extensive livestock production employs natural resources through its land use and land-use change, affecting the natural resource cycles. This form of production mainly involves ruminants, which are highly influencing the carbon and nitrogen original equilibrium. One of the downside effects of extensive production is the burning of land, which is commonly used to manage and regulate space for pastures. The controlled burning can actually help with the control of more destructive fires, and prompt the growth of a type of vegetation resistant to fire (perennial grasses) that provides regrowth for livestock, this means that not all fires are damaging and that it depends on the context, however when the control over them is low, the environment is heavily impacted. However, when considering land use, in particular controlled burning, it needs to be taken into consideration how the clearing of forests also generates a complex pattern in the C fluxes, making it hard to measure its CO2 emissions. Nonetheless, the IPCC provided a calculation to measure the accountability of deforestation for climate change, which is 1.6 billion +- 1 billion tonnes of CO2 each year (between 1980 and 1989), of which around 60 percent is from forest conversion, while the rest was delayed emissions related to oxidation of the biomass of previous years (Steinfeld and Wassenaar, 2007). Although the numbers talk about a period that is no longer adequate, we can still consider it as a benchmark from which to start, as the clearing of the forests to give space to livestock is still a practice, which is present in a lot of countries around the world. Alongside carbon dioxide there are other gases that are emitted in the production and management of livestock. When discussing nitrogen, there is a concept that needs to be clear before approaching its effect on nature. Nitrogen is a gas that is already present in nature, but the quantity naturally present on earth would have not allowed a big enough production of livestock products for the increasing population, so reactive N (i.e. a variety of nitrogen compounds that support growth both directly and indirectly) has been fixed in grass, having, however, the downside effect of also impoverishing ecosystems. The effects of nitrogen and methane when released into the atmosphere will later be discussed in depth.

1.1.2 Intensive form of livestock production

The immediate benefit that is thought of when discussing intensive livestock production is that this type of practice requires less land per unit of output as well as the feed, which is also produced with an intensive approach, reducing even more the land occupied. However, to maintain a certain quality of the product at the pace of the intensive production, this practice requires a high intake of external inputs, like nutrients, water, and energy. This intensive use of resources paired with their mobilization affects greatly the natural cycles.

One significant difference from the extensive approach, is that at all stages of production the intensive approach requires more fossil fuels. The fossil fuels mentioned refers to the ones used to manufacture fertilizers (as previously discussed, fertilizers are used mainly in the crop production, and the main use of these crops is to feed animals, so the use of fertilizers can be traced back to livestock). Furthermore, the feed crop that needs more N fertilizer is maize, which has more than half of the production that is directed to the feeding of livestock. Other feed crops that use a significant quantity of N fertilizers are barley and sorghum and also some oils, which are mainly use for livestock purposes, such as rapeseed, sunflower and soybean (i.e. 110.000 tonnes of N fertilizer are used every year in Brazil for soybean alone and 1.3 billion tonnes in China (Steinfeld and Wassenaar, 2007)). Fossil fuels are also used on-farm, for the production of the feed itself, like forage for ruminants and concentrated feed for poultry and pigs and these also includes the fossil fuels to produce fertilizers, seeds, herbicides, pesticides, diesel for machinery and general electricity. Other factors that contributes to the use of fossil fuel in the intensive approach are processing and transportation, for example the processing of soybeans involves energy-intensive physical and chemical oil extraction. The high demand of animal products generates a high demand in feed production, this increase in demand cannot be met only by increasing the intensification of feed production, but also by the expansion of cropland, which will lead to the replacement of forests alongside for pasture reasons. When soils get cultivated to produce feed the transformation immediately causes a loss of C as it gets into managed land. With regards of methane the emissions in the intensive approach if compared with enteric fermentation (typical of the extensive approach) is relatively low, however, substantial emissions are released from the anaerobic decomposition (a technology in which organic materials are placed in a container and broken down by microorganisms to later generate biogas) of organic material in livestock manure, especially when held in liquid from (i.e. lagoons and holding tanks). The issue regarding nitrogen in the intensive approach is that the chemical in the fertilizers used and animal concentration disrupts ecosystem equilibrium. Anthropogenic activities have doubled the amount of N presence in the land-based N cycle. However, it needs to be taken into consideration that measuring the amount of N generated by the different systems is not as straight forward as might thought. This is mainly because there are a lot of variables that influence the emissions of such gas, for example the temperature and soil moisture, the chemical balance of the soil and the timing, form, and mode of application of chemicals. The low N assimilation in the intensive approach is aggravated by the spatial concentration of a very large number of animals and very N-rich diets. Its concentration also depends on the management of the manure, whether it is applied in excess in the nearby land, discharged in the water or lost in stored manure or even sold as fertilizer.

In the following tables (table 1 and table 2) it can be seen the different impacts that the extensive production approach and the intensive production approach in the emissions of carbon dioxide and nitrogen.

Process	Impact on C cycle	Contribution from extensive systems[a]	Contribution from intensive systems[a]
N fertilizer production	Addition of atmospheric CO_2	—	0.04
On-farm fuel use	Addition of atmospheric CO_2	—	~0.09
Savannah burning	Changing carbon distribution in vegetation Contribution to climate change	Majority of burned area worldwide	—
Pasture desertification	Soil carbon loss Addition of atmospheric CO_2	~0.1	—
Deforestation	Soil and vegetation carbon loss Addition of atmospheric CO_2 Changing local carbon cycle	~1.7	~0.7
Soil tillage	Soil carbon loss Addition of atmospheric CO_2	—	~0.02
Soil liming	Addition of atmospheric CO_2	—	~0.01
Enteric fermentation	Addition of atmospheric CH_4	1.6	0.20
Methane from manure	Addition of atmospheric CH_4	0.17	0.20
Processing	Addition of atmospheric CO_2	—	0.01–0.05
Transport	Addition of atmospheric CO_2	—	~0.001

[a]Quantified contributions concern additions to and removals from the atmospheric pool and all are expressed in billion tonnes CO_2 equivalent.

Table 1. Summary of current impacts on the carbon cycle from the intensive and the extensive livestock production. Source: (Steinfeld and Wassenaar, 2007)

Process	Impact on N cycle	Estimated contribution from extensive systems[a]	Estimated contribution from intensive systems[a]
Mineral fertilizer application	Eutrophication of aquatic systems	—	8–10
	Addition of atmospheric N_2O	—	0.4 (0.2)
	Volatilization/deposition of NH_3	—	3.1
Leguminous feed cropping	Addition of atmospheric N_2O	—	0.5 (0.2)
Extensive grazing	N loss from local terrestrial pools	18	—
	Addition of atmospheric N_2O	1.8 (0.8)	—
	Volatilization/deposition of NH_3	6	—
Manure management	Addition of atmospheric N_2O	1.3 (0.6)	0.5 (0.2)
	Volatilization/deposition of NH_3	11	7
	Eutrophication of aquatic systems	More than 10[b]	

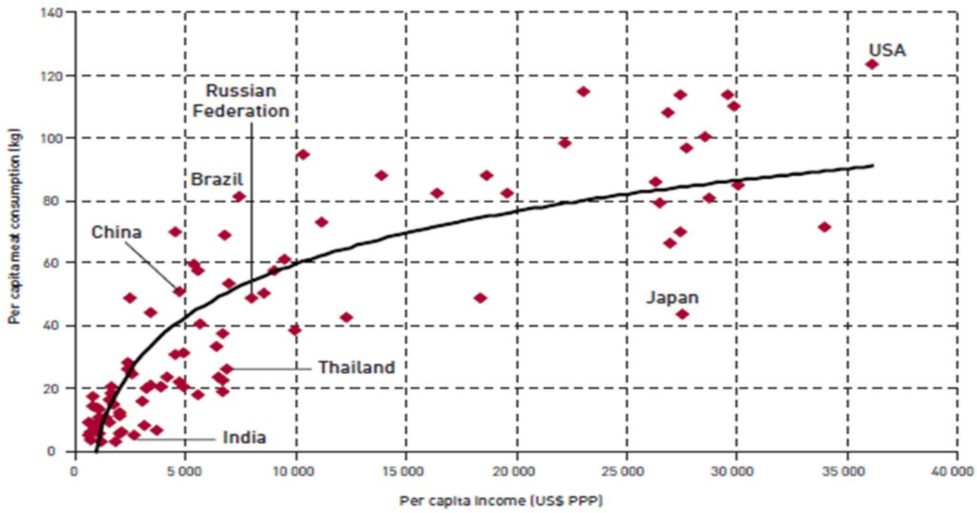
[a]Quantified contributions are expressed in million tonnes N per year, except for additions of atmospheric N_2O, also expressed in billion tonnes CO_2 equivalent (between parentheses).
[b]Overall estimate based on mid-1990s figures but lacks information on the importance of direct discharge of manure to water.

Table 2. Summary of current impacts on the nitrogen cycle from the intensive and the extensive livestock production. Source: (Steinfeld and Wassenaar, 2007)

1.2 Factors that influence livestock

- Changes in Demographic: an increase in population consequently influences the demand for food. This increase, however, does not involve the population of developed countries, which seem to be stagnant, but the developing countries. In fact, 95% of this growth is addressed to the developing countries (Steinfeld et al., 2006). One factor influencing the growth rate of the population is the late mortality of people (the population who is over 60 years old is increasing). Another factor is urbanization. Urbanization changes the patterns of nutrition of a population, as being forced to stay away from home during lunch time brings the population to consume precooked meals and fast food, which usually involves a higher amount of animal protein than home cooked meals.

- Economic growth: economic growth grows demand for livestock products, but why? First, in the developing countries (thanks to urbanization and industrialization) emerged the middle class, with an income high enough to allow them to purchase above their basic needs. Furthermore, income has a high elasticity with regards to livestock demand (higher income means higher demand of animal products, till it becomes stable), which also means that the gap in the consumption between developed and developing countries will decrease as can be seen in graph 2.



Graph 2. Relationship between meat consumption and per capita income. Source: World Bank (2006) and FAO (2006)

- Nutrition transition: this phenomenon occurs in the developing countries, where the accessibility to a richer diet (the one currently available in the developed countries) is growing rapidly, which often leads to overnutrition given the sadden change and the consequent difficulty to get used to it. What does this have to do with livestock? The developing countries cited are shifting from diets heavily based on vegetables and cereals towards diets with pre-processed food and animal origin food.
- Technological change: technological change brought advanced ways of breeding (i.e. hybridization and artificial insemination, which allowed the growth of the bulk production and the consequent use of economies of scale to cut down the costs) and feeding technologies, leading to a growth in production. New fertilizers and irrigation systems, alongside to improved varieties upgraded the crop fields, switching from the feed locally available to feed concentrates, transforming feed into a tradeable product. This form of crop is used mainly for its cheap price, making the most convenient source of food to feed livestock and consequentially expanding the land used to produce concentrate feed to the expanse of other essential habitats, such as the rainforest. Finally, new technologies made easier the distribution and production of the final animal products. The high supply and availability of animal products led also to lower prices, making these products accessible to poorer countries too.

Livestock is growing faster than the rest of agriculture practises, thanks to the rise of income, development, and the shift in its purpose from economic assets to food, especially in the developing countries. An example that represents these changes to the fullest is China, which accounts for 57 percent of the increase in meat production between the developing countries (Steinfeld et al., 2006). The same goes for dairy products, even if in smaller amounts, where the current leader in consumption is India. The danger with this increase is that it is thought that it will not slow down for another 10-20 years, and the countries more involved in it are also the ones gaining more trading power, such as Brazil, India and China (Steinfeld et al., 2006). These countries alone, account for three-quarters of the growth in meat and dairy products in all developing countries (table 3).

Developing country trends in livestock production in 2005

Country Group/Country	Meat (million tonnes)	Milk (million tonnes)	Percentage of developing country production	
			Meat	Milk
Developing countries	155.0	274.1	100.0	100.0
China	75.7	28.3	48.8	10.3
Brazil	19.9	23.5	12.8	8.6
India	6.3	91.9	4.1	33.5

Table 3. Trends in livestock of the developing countries. Source: FAO 2006

In the livestock sector there has been also a shift in the geographical sense, which means that the locations are not chosen anymore according to the natural constrains, but instead, according to the opportunity cost of land and access to markets.

1.3 Livestock's effect on climate

Livestock is responsible for the emission of a fair amount of greenhouse gases because of their respiratory process and for their digestive process, which is mainly considered because of the high quantity of methane (CH4) released. Its emissions, however, do not stop only at their existence. To maintain and manage livestock, a lot of land is necessary, which means that when calculating how much it is really contributing to the emissions, it is necessary to also consider, all the forests cleared for pastures, the gases emitted during the production of the final products, and all the emissions from the production of the feed to the distribution of the meat and dairy products into the market. One of the many side effects of livestock that contributes to climate change, is air pollution, in particular with the emission of ammonia (a compound of nitrogen and hydrogen, NH3), which is released into the air due to excreta. What causes air pollution? A group of gases get absorbed by the earth and later gets into the water, which then evaporates and turns into acid rain and endangering respiratory systems. When considering carbon, which is the main source of GHGs emissions, it is crucial to stress how it is also found in nature.

But while in nature it has a cycle that follows, in order to keep a certain balance in the emissions, the amount produce by humans goes only one way, meaning that once it is out in the atmosphere it stays there and there is no cycle that allows it to be absorbed back into nature. Between the anthropologic actions that produce carbon, livestock does not usually come directly on top of someone's mind, but if in the calculation is also considered the indirect emissions, such as the burning of fossil fuels to produce fertilizers, methane from animal manure, land degradation, fossil fuel used during feed and animal production, land changes for feed production and fossil fuel used to keep the products refrigerated the percentages of accountability for climate change changes drastically, bringing such activity to one of the most responsible.

1.3.1 Livestock's indirect emissions

- The first element that will be taken into consideration is fertilizers. Fertilizers are used frequently especially for the production of concentrated feed and they are mainly composed of nitrogen (which as mentioned before, is a GHG that has a warming potential way higher than carbon dioxide). Furthermore, the fossil fuels used for their production correspond to 41 million tonnes of CO2 every year. How much are fertilizers related to livestock? As it can be seen in table 4 below, the majority of their production is directly associated to feed and pastures.

Chemical fertilizer N used for feed and pastures in selected countries

Country	Share of total N consumption	Absolute amount
	(percentage)	*(1 000 tonnes/year)*
USA	51	4 697
China	16	2 998
France*	52	1 317
Germany*	62	1 247
Canada	55	897
UK*	70	887
Brazil	40	678
Spain	42	491
Mexico	20	263
Turkey	17	262
Argentina	29	126

* Countries with a considerable amount of N fertilized grassland.

Table 4. Fertilizers N used for feed and pastures in the countries which are the main users of them. Source: FAO 2002

- As mentioned before another element that produces CO2 through fossil fuels is the energy used for livestock. The energy is used mainly for the production of feed, but also for the transport, machinery and electricity, and it exceeds the emissions from fertilizers.
- Another one is land use, not only when it is considered as land occupied by livestock, but also considering the emissions released when transformed into land useable for livestock. For example, when forests are cut down or burned to make some space to livestock, the amount of the carbon emitted is way more than from the livestock itself. An example is Savannah, that in 2000 burned 4 million km2 (Steinfeld and Wassenaar, 2007). Even if the CO2 emitted during the burning of the Savannah is not considered in the total global carbon emissions, as it is recaptured in grass re-growth, there are other gases and aerosols that have been released by the biomass. Desertification of pastures also causes a decrease in productivity and vegetation cover and changes C (carbon) and nutrient cycles. This soil erosion and nonrenewal of decaying organic matter stocks causes a great

emission of CO_2. As livestock occupies around two thirds of land and land desertification comes mainly by grazing land (land covered in grass, suitable for livestock), C loss reaches about 10 tonnes per hectare, meaning 100 million tonnes of CO_2 per year (Steinfeld and Wassenaar, 2007). Global warming is also an issue as it is making the decay of grass faster, which would mean more loss of C from the soil. Another factor is the deforestation caused by livestock which is occurring to a high extent in Latin America. Latin America accounts for the highest loss of forests and the main reason for the clearing of them is to create space for pasture's ranching. Also considering that forests take part into the conversion of CO_2 (i.e. cycle that absorbs the carbon emitted and transforms it into oxygen), it means that from erasing them, a big system of capturing CO_2 is eliminated. Even though, calculating the emissions coming from forest clearing is complicated and the fact that it is difficult to directly address it to livestock, we know that one of the main forces that drives the sweeping of forests is the necessity to give space to animal production. Estimates says that forest clearing for animal production and feed product is responsible for 2.4 billion tonnes of CO_2 per year (Steinfeld et al., 2006).

- Animal manure: another factor responsible for GHG emissions is manure, in particular for the emissions of methane, the form of management that is more damaging in this sense is the liquid form. In this form the amount of CH_4 increases drastically as it affects the growth of the bacteria that causes it. In this case, the animal that is the most damaging is the pig, which is responsible for nearly half of the emissions from manure emissions. Manure decomposition is responsible for the emissions of 17.5 million tonnes of CH_4 annually (Steinfeld et al., 2006).
- Livestock processing and refrigerated transport: Even though is difficult to trace the emissions of this sector back to livestock, given that all the emissions would be of indirect nature, it is possible to confirm that it is still responsible for millions tonnes of CO_2. When discussing transport, it is not considered in short distances to retailers and consumers, but in long distances, more specifically, in delivery of feed to animal production sites and delivery of animal products to consumers markets. The main contributor to these emissions is soybean, especially from

Brazil to Europe, which roughly accounts for 32 thousand tonnes of CO_2. While for meat transport the numbers go up to 500 thousand tonnes of CO_2, if we consider only sea transport.

1.4 The main GHGs emitted by Livestock

Before venturing in the disclosure of some of the greenhouse gases, it needs to be clarified that the respiration of the livestock in some of the following calculation is not included in the CO_2 emissions emitted, because it is considered as part of the biological cycle. However, the equilibrium of this biological cycles is clearly put into danger when the feedcrops are badly managed and there is overgrazing, as the vegetation is not able to re-grow fast enough to absorb the CO_2 that livestock “breathes out”.

The differences between the calculations of the different sources will be later explained in depth.

- Methane: One gas that is mainly caused by livestock, in particular ruminants, is methane as a result of their digestive processes, through the so-called enteric fermentation (table 5). Its emissions, however, do not equal in every country, as it is highly dependent on other factors other than just the animal itself. It also depends on quantity and quality of feed, animal body weight etc. Taking this into consideration and applying as detailed as possible all the guidelines of the IPCC it is possible to credit livestock with 86 million tonnes of CH_4 (methane) annually (Steinfeld et al., 2006).

Global methane emissions from enteric fermentation in 2004

Region/country	Dairy cattle	Other cattle	Buffaloes	Sheep and goats	Pigs	Total
	Emissions (million tonnes CH_4 per year by source)					
Sub-Saharan Africa	2.30	7.47	0.00	1.82	0.02	**11.61**
Asia *	0.84	3.83	2.40	0.88	0.07	**8.02**
India	1.70	3.94	5.25	0.91	0.01	**11.82**
China	0.49	5.12	1.25	1.51	0.48	**8.85**
Central and South America	3.36	17.09	0.06	0.58	0.08	**21.17**
West Asia and North Africa	0.98	1.16	0.24	1.20	0.00	**3.58**
North America	1.02	3.85	0.00	0.06	0.11	**5.05**
Western Europe	2.19	2.31	0.01	0.98	0.20	**5.70**
Oceania and Japan	0.71	1.80	0.00	0.73	0.02	**3.26**
Eastern Europe and CIS	1.99	2.96	0.02	0.59	0.10	**5.66**
Other developed	0.11	0.62	0.00	0.18	0.00	**0.91**
Total	**15.69**	**50.16**	**9.23**	**9.44**	**1.11**	**85.63**
Livestock Production System						
Grazing	4.73	21.89	0.00	2.95	0.00	**29.58**
Mixed	10.96	27.53	9.23	6.50	0.80	**55.02**
Industrial	0.00	0.73	0.00	0.00	0.30	**1.04**

* Excludes China and India.

Table 5. Global methane emissions from ruminants. Source: (Steinfeld et al., 2006).

- Nitrogen: Nitrogen is present in nature and essential for the existence of both vegetation and animals, however its presence has been modified by the human hand, with the help of, for example, synthetic fertilizers. The quantity of nitrogen that plants can absorb is not high, and the current excess of it, leads to the so-called “nitrogen cascade” (Steinfeld et al., 2006). The nitrogen cascade means an excess of nitrogen that damages ecosystems and alters their functioning. Furthermore, this type of gas is the main cause of the ozone layer and has a big impact on global warming. It accounts for 7-8 million tonnes of N/yr, for which 70 percent, agriculture and livestock production can be held accountable (Steinfeld et al., 2006). Nitrogen comes also in the form of ammonia, which is a dangerous air-polluting gas, and which is estimated to reach 116 million tonnes of N/yr by 2050 (Steinfeld et al., 2006). A significant amount of these emissions can be found in the developing countries, as the fertilizers generally used are still designed in a way which causes a great loss of nitrogen into the atmosphere, this is because of the average temperature characteristic of these countries and the use of urea (i.e. nitrogen-containing substance, present in 50 percent of the nitrogen fertilizers used in the developing countries[11]) and ammonium bicarbonate (inorganic compound, which in China, is used in around 40-50 percent of the fertilizers) which has a high volatility, meaning that it evaporates into the atmosphere easily. According to the Food and Agriculture Organization, around 20-25 percent of the fertilizers used can be traced back to livestock. The main issue involving nitrogen is its low assimilation efficiency, which is around only 70 percent when it is about crops, but when it is about livestock the numbers are even lower. N enters livestock trough feed, and is expelled through excretion, but the efficiency varies according to the different species. Some of it actually re-enters the crop production cycle, but the quantity entering the cycle is still very low.

Here are some percentages of the greenhouse gases that can be directly or indirectly imputed to livestock production and management and all the activities that can be traced back to livestock and how much is their involvement in the overall anthropogenic emissions:

Carbon Dioxide: 9 percent of global anthropogenic emissions (deforestation for pasture and feed crops, and pasture degradation).

Methane: 35-40 percent of global anthropogenic emissions (enteric fermentation and manure)

Nitrous Oxide: 65 percent of global anthropogenic emissions

Ammonia: 64 percent of global anthropogenic emissions (changes highly according to the environment and surroundings, making it more a local issue, than a global one).

All of this calculation have been done according to the FAO and IPCC regulations, however, as mentioned before and as it will be seen later in this chapter, there are other studies and organization who disagree with some rules applied in the measurement of the emissions.

[11] More information can be found in the FAO website: http://www.fao.org/3/a-a0701e.pdf

Role of livestock in carbon dioxide, methane and nitrous oxide emissions

Gas	Source	Mainly related to extensive systems (10^9 tonnes CO_2 eq.)	Mainly related to intensive systems (10^9 tonnes CO_2 eq.)	Percentage contribution to total animal food GHG emissions
CO_2	**Total anthropogenic CO_2 emissions**	**24 (~31)**		
	Total from livestock activities	**~0.16 (~2.7)**		
	N fertilizer production		0.04	0.6
	on farm fossil fuel, feed		~0.06	0.8
	on farm fossil fuel, livestock-related		~0.03	0.4
	deforestation	(~1.7)	(~0.7)	34
	cultivated soils, tillage		(~0.02)	0.3
	cultivated soils, liming		(~0.01)	0.1
	desertification of pasture	(~0.1)		1.4
	processing		0.01 – 0.05	0.4
	transport		~0.001	
CH_4	**Total anthropogenic CH_4 emissions**	**5.9**		
	Total from livestock activities	**2.2**		
	enteric fermentation	1.6	0.20	25
	manure management	0.17	0.20	5.2
N_2O	**Total anthropogenic N_2O emissions**	**3.4**		
	Total from livestock activities	**2.2**		
	N fertilizer application		~0.1	1.4
	indirect fertilizer emission		~0.1	1.4
	leguminous feed cropping		~0.2	2.8
	manure management	0.24	0.09	4.6
	manure application/deposition	0.67	0.17	12
	indirect manure emission	~0.48	~0.14	8.7
Grand total of anthropogenic emissions		**33 (~40)**		
Total emissions from livestock activities		**~4.6 (~7.1)**		
Total extensive vs. intensive livestock system emissions		**3.2 (~5.0)**	**1.4 (~2.1)**	
Percentage of total anthropogenic emissions		10 (~13%)	4 (~5%)	

Note: All values are expressed in billion tonnes of CO_2 equivalent; values between brackets are or include emission from the land use, land-use change and forestry category; relatively imprecise estimates are preceded by a tilde.
Global totals from CAIT, WRI, accessed 02/06. Only CO_2, CH_4 and N_2O emissions are considered in the total greenhouse gas emission.
Based on the analyses in this chapter, livestock emissions are attributed to the sides of the production system continuum (from extensive to intensive/industrial) from which they originate.

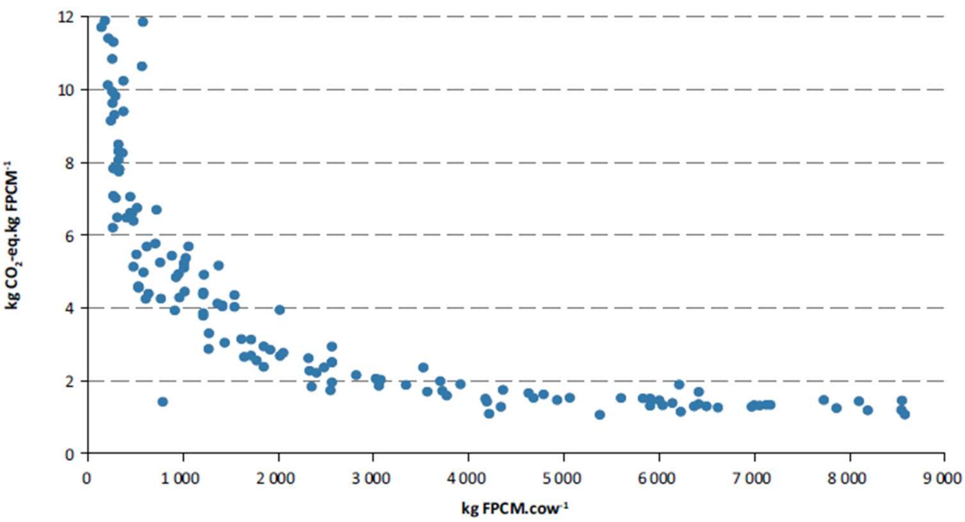
Table 6. Role of livestock in carbon dioxide, methane and nitrous oxide emissions. Source: Livestock Long Shadow (Steinfeld et al., 2006).

1.5 LOSS FROM THE LIVESTOCK: PRODUCER POINT OF VIEW

The release of GHG in the atmosphere represents for the livestock producer a loss in energy, nutrients and soil organic matter, which is caused by the inefficiency in the use of initial inputs and resources, damaging the economic viability and the efficiency of the supply chains. When considering methane (CH4), the main loss is related to the energy in the production system, which means that some energy is lost instead of being assimilated by the animals in the ingestion of feed. Feed is the main cost item in the mixed systems, hence the loss of CH4 causes to producers a damage in production, alongside the environmental damage, which includes the resources used by the feed production (i.e. water, land, fossil fuels) that go to waste with the loss of methane. Another loss of energy comes from manure, but it can be recovered by a biogas digester (large tank in which organic matter is decomposed into biogas, through the anaerobic digestion). Manure emissions can be mostly recovered, while enteric emissions cannot. When it comes to Nitrous Oxide, its loss is also a high cost for producers, as it is a key element to improve yield and to keep it from getting into the atmosphere, some supplies of reactive N to the plants (through manure of synthetic fertilizers) or preservation of it in the soil comes with costs. Furthermore, these activities require high level of fossil fuels consumption. These emissions involve manure storage and processing and they are responsible for the acidification and the eutrophication of natural habitats. Even though on-site energy consumption has a low cost, there are some cases in which the costs are high, an example is in the intensive milk-production systems. The increase of energy use efficiency can be reached by an adoption of better management practices, energy saving devices, and reduce emissions and costs for farms and processing plants. Another aspect to keep into consideration is soil organic matter, which is the primary form of carbon in soils and it serves many functions, but it is also often lost through inadequate agricultural practices or pasture degradation as the productivity of the land decreases over time. Land-use which happens to be one of the contributors for the emissions in this sector accounts for roughly 9.2 percent of total livestock emissions, of which 6 percent is attributed to pasture expansion and the rest to feed crop expansion (Gerber et al., 2013). This element changes a lot in relevance according to the region and the supply chain it is referring to, for example, in is quite high in the beef production because of the pasture expansion and in the chicken production for the soybean expansion, which is highly traded at the international level, meaning that some of the emissions are attributed to the production units around the world, while for pasture expansion the emissions are attributed directly to the local production. However, drivers of land-use changes and methods to attribute its emissions are still highly debated.

1.6 PRODUCTIVITY VS. EMISSIONS INTENSITY

Up to a high level of productivity, emission intensity decreases as yield increases. In the milk production case, high-yielding animals producing more milk per lactation usually show a lower emission intensity. This is because, the emissions are spread over more units of milk, hence the maintenance requirements for the animals are spread out; the productivity gains are reached thanks to improvements in technologies and practices, which consequently leads to a reduction of emissions; and lastly the productivity gains are also achieved through the use of the resources with a productive purpose rather than to maintain the animals, which reduces the amount of biomass used per unit of milk produced. This means that improving the production coming from low-yield ruminants would not only increase productivity, but also decrease emissions. This example can be seen in the following graph 3.



Graph 3. Relationship between productivity and emission intensity of milk (country averages). Source: (Gerber et al., 2013).

However, this behaviour is not necessarily adopted by all species. In fact, monogastric species, in particular pigs have a relationship between production intensity and emissions that is different, as it forms a u-shape. This can be explained by the fact that backyard systems have low emissions, and on the other end, industrial system, even though they produce a higher amount of emissions it is still relatively small if compared to mixed system, where the emissions reach their peak, as this system combines high feed emissions intensity with relatively high feed conversion ratios.

1.7 DISCREPANCIES IN THE PERENTAGES

Up till now, in this chapter, livestock has been held responsible only of 18 percent of annual global CO2 emissions, but some research actually brings the number way up to at least 51 percent of annual global GHG emissions (Goodland and Anhang, 2009). Before following with the explanation of the previous statement, it is crucial to stress, how these calculations are not easy to do, as the variables to keep into consideration are numerous and change according to a lot of factors, such as the location of the livestock. However, all the emissions which were calculated up till now with data that was not certain, has been kept to the minimum, in order to give a conservative result. According to Goodland and Anhang (2009), in the previously mentioned researches there have been some emissions that are missing, some emissions which where misallocated into other sectors and some that where completely uncounted. These emissions include also the amount emitted to keep the animals alive and some for the transport and process of the end products. One of the elements that the FAO did not take into consideration is the breathing of the livestock. As mentioned before, it was not considered for the main reason that the breathing was part of the cycle to keep CO2 emissions in equilibrium alongside the photosynthesis of the plants. However, this equilibrium has never been stable, and now it is even less so, given the increase in livestock and the decrease of the earth's photosynthetic capacity caused by the constant cutting of the forests. Livestock respiration is accountable for 21 percent of anthropogenic GHG emissions as physicist Alan Calverd estimated (Goodland and Anhang, 2009). To clarify, livestock's respiration must be kept into consideration mainly because the oxidation of the soil of the land and the respiration surpass the carbon absorbed by photosynthesis by 1-2 billion tons per year (Goodland, 2010). It is also considered as the foregone reduction of emissions, caused by the erasing of forests, which causes the reduction in the quantity of CO2 absorbed by the plants, and this has the same impact as an increase in emissions. Regarding the land, livestock's population is increasing so rapidly that there is a necessity to cut down forests as that is the only land left available. However, this cuts the amount of carbon stored from 200 to 8 tons per hectare (Goodland and Anhang, 2009). Regardless of the capability of livestock to store some carbon in their skin without realising it, this amount is so little compared to the loss caused by the erasing of the forests that it does not matter. So, the last calculations count the loss regarding the inability of the photosynthesis to happened, adding 4.2 percent of annual GHG emissions worldwide. When mentioning methane, it needs to be explained that its global warming potential (GWP), which is a 72, is way higher than CO2 in a twenty-year time span. However, there has been some debate over the most appropriate time span to use. Up till now, the time frame always used has been the 100 years' time span, as it represents the amount of time that CO2 takes to reach its half-life span into the atmosphere before it gets disperse. This specific time frame though is not beneficial to address the damaging potential of the GHGs as, with a 100-time span, the GWP of methane lowers drastically to 25, given that its half-life in the atmosphere is around 8 years before dispersion. For this specific reason, even the IPCC approved the 20-year timeframe, in order to address properly the dangerousness of all the greenhouse gases. Furthermore, to prove how the percentage, regarding the involvement in the GHGs emissions, attributed to livestock is most certainly higher than the one previously discussed, it needs to be considered that the previous calculations were made at the beginning of two decades ago, and there has been a significant increase in livestock since then, 12 percent, which consequently increased the amount of GHG emissions to a 4 percentage. The previous research also did not include some data, that represents high amounts of GHG emissions, such as marine organisms, of which half of it is destined to feed livestock. To further proof the validity of the last calculation, there are other elements that were not counted in the total amount of emissions of GHGs, these includes fluorocarbons, used to cool livestock products; cooking, which involves carbon and kerosene in developing countries; the disposal of huge quantities of liquid and non-liquid waste, which will be later disposed in landfills, incinerators and waterways; production and distribution of the by-products and packaging for livestock products and at last, carbon intensive medical treatments linked to the consumption of livestock products. All of these sources are gathered below in table 7.

Uncounted, Overlooked, and Misallocated Livestock-related GHG Emissions	Annual GHG emissions (CO_2e)	Percentage of worldwide total
	million tons	
FAO estimate	7,516	11.8
Uncounted in current GHG inventories:		
1. Overlooked respiration by livestock	8,769	13.7
2. Overlooked land use	≥2,672	≥4.2
3. Undercounted methane	5,047	7.9
4. Other four categories (see text)	≥5,560	≥8.7
Subtotal	≥22,048	≥34.5
Misallocated in current GHG inventories:		
5. Three categories (see text)	≥3,000	≥4.7
Total GHGs attributable to livestock products	≥32,564	≥51.0

Table 7. Uncounted, Overlooked and misallocated livestock-related GHG emissions from the FAO assessment. Source: Livestock and Climate Change what if the key actors in climate change are cows, pigs and chicken. (Goodland and Anhang, 2009)

Aside from the FAO data, there are the IPCC guidelines of 2006, regarding the measurement of GHG emissions, which are based on the inventory, and the annual population of each animal type is multiplied by species- and region-specific emissions factors. These factors are derived by keeping into consideration the quality and the management of livestock at a regional level, and they include feed intake quantity and quality, amount of energy used for growth, foraging, etc. The issue with the bottom-up inventories (used in the IPCC guidelines) is that they are outdated, meaning that they do not take into consideration the changes that involved livestock in the most recent years. Such changes include the use of various manure management systems; animal traits that have changed due to the increase in the use of improved breeds and animal feed quality and quantity. It the following figure, it is possible to see the amount of methane produced by the global livestock in 2011 following said guidelines. The valuations are based on the guidelines of IPCC of 2006, with some necessary revisions that take into considerations the changes mentioned above.

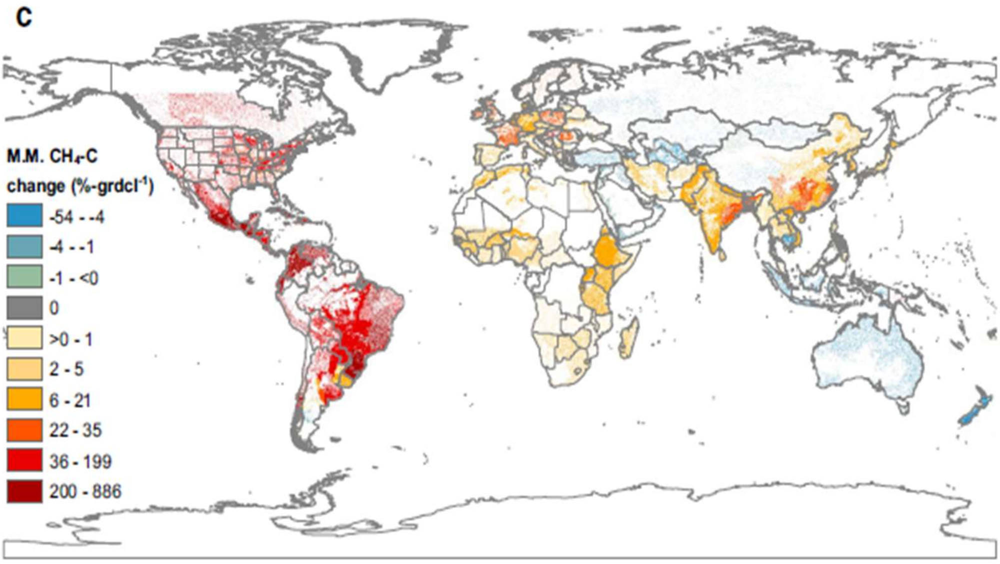


Figure 1. Percentage in global livestock methane emissions with revision, for the total enteric fermentation and manure management methane emissions in 2011. Source: (Wolf, Asrar and West, 2017)

The 18 percentage, representing the emissions caused by livestock if compared with the overall global emissions, came from the FAO in 2006, and even this number caused alarm when it was disclosed, as it represented a percentage higher than the one related to transport. It is no surprise then, that when the Worldwatch Institute declared that indeed the percentage regarding animal agriculture was not 18, but at least 51, it came as a shock. Such a high percentage means that by changing the management of such sector or diminishing the demand of its products the problem of climate change would be quickly contained. One of the major differences between the percentages is that the higher one keeps into consideration the loss brought by the replacement of forests with fields for feed or the grazing of livestock, which does not allow the photosynthesis to happen, and indirectly implies how the regeneration of forests could mitigate climate change drastically. Furthermore, FAO heavily base its statement on data from

Minnesota animal agriculture system, which is not fair, if considered that the largest livestock production happen in developing countries, where the approaches are way different and less sophisticated, hence with higher emissions. An argument that went against the report of the Worldwatch Institute, stated that their discovery was not peer-reviewed, but the authors, besides having participated to the FAO report themselves also proofed the fact that they were indeed peer-reviewed and it has been later supported by UNESCO too. Furthermore, to increase the suspicion that the first percentage (18 percent) is not realistic, comes the fact that FAO later partnered with the International Meat Secretariat and the International Dairy Federation and immediately after stated that how livestock accounts for 14.5 percent of the overall anthropogenic emissions and not 18 anymore. Even though, this is only a conspiracy theory, it is clear how the FAO assumptions are clearly wrong, and even if I am not wholeheartedly sure that even the Worldwatch Institute is right, I believe that a percentage nearer to the latter is more accurate when assessing the leverage that livestock has when addressing climate change.

To wrap up the concepts and numbers cited in this chapter it can be said that livestock have an immense impact on climate change and the overall environment, regardless of the discrepancies in some of the percentages presented. For this reason, an action to slow down livestock and the production of its products is necessary if we want to diminish the damages that are coming from climate change efficiently. The possible solutions will be discussed in chapter 2.

Chapter II: How to reduce livestock and its products?

It is safe to say that trying to find a way to reduce livestock and its products can be tricky as it covers a crucial economic role for around 60 percent of rural households in developing countries, contributing to the life of 1.7 billion poor people, of which 70 percent are women (Food and Agriculture Organization[12]). Livestock does not only provide food for this population, but it also guarantees a way of transport and fuel for crop production. This leads livestock to be one of the elements that helps reduce poverty, fight food malnutrition, and improve resilience. Having said that, it is clear that thinking of reducing livestock or stopping the production of its products sounds not only complicated, but also wrong. However, as mentioned in chapter 1, the amount of greenhouse gases emitted by livestock is dangerously high, meaning that an action needs to be taken against its constant increase in demand and current management. In chapter two, there will be an overview on various techniques, models and actions that could lead us towards a future with less livestock's emissions. Starting from previously famous taken actions, such as the carbon tax and the cap and trade system, which have been widely theorized and later applied, the analysis will venture towards more innovative methods of mitigations of GHG emissions and models specifically studied to offer an insight on the actors that have the biggest impact on the planet and how to reduce them. Furthermore, it will be discussed how possible actions towards livestock could influence the producers and the consumers, and how the reaction to changes can be tamed through incentives and other types of actions from the government. The options to mitigate climate change mentioned here, are not all realistically adoptable, especially if a serious change in the population mindset is not reached, however, for the sake of completeness they have been included anyway.

2.1 Previously taken actions

So far, the actions taken to reduce greenhouse gases emissions have never directly only involved livestock, but more other anthropogenic actions, such as fossil fuel consumptions. The two major systems that have been applied and are still being used,

[12] Food and Agriculture Organization, http://www.fao.org/home/en/

regarding the control of GHG emissions, are the cap and trade system and the carbon tax.

2.1.1 Cap and Trade System

The cap and trade system consists of a limit on the amount of emissions that a company is allowed to emit, the so called "cap", and the possibility to sell the remaining allowances that the company may have left or buy from another company in case it went over the limit, and this part is the "trade". Each allowance gives the holder the right to emit either one tonne of carbon dioxide or the equivalent amount for the two more powerful greenhouse gases, nitrous oxide or perfluorocarbons. This system has always been monitored by the different states, and that caused the main issue of not being able to catch the constant shift in supply and demand for the allowances. This resulted in an excess of allowances and the emissions not to reduce. However, the system has been perfectioned with time, and it is still part of the environmental policy in many countries. An example is Europe, who is keeping on targeting a bigger reduction factor throughout the years, in the following phase (phase 4, between 2021 and 2030) the goal is to reach the annual linear reduction factor of 2.2%[13]. To make more effective the cap and trade system, Europe decided also to approach the emissions from the aviation sector separately, as they cause a huge amount of emissions every year. However, for phase 4 the same reduction factor of the other stationary sectors has been applied.

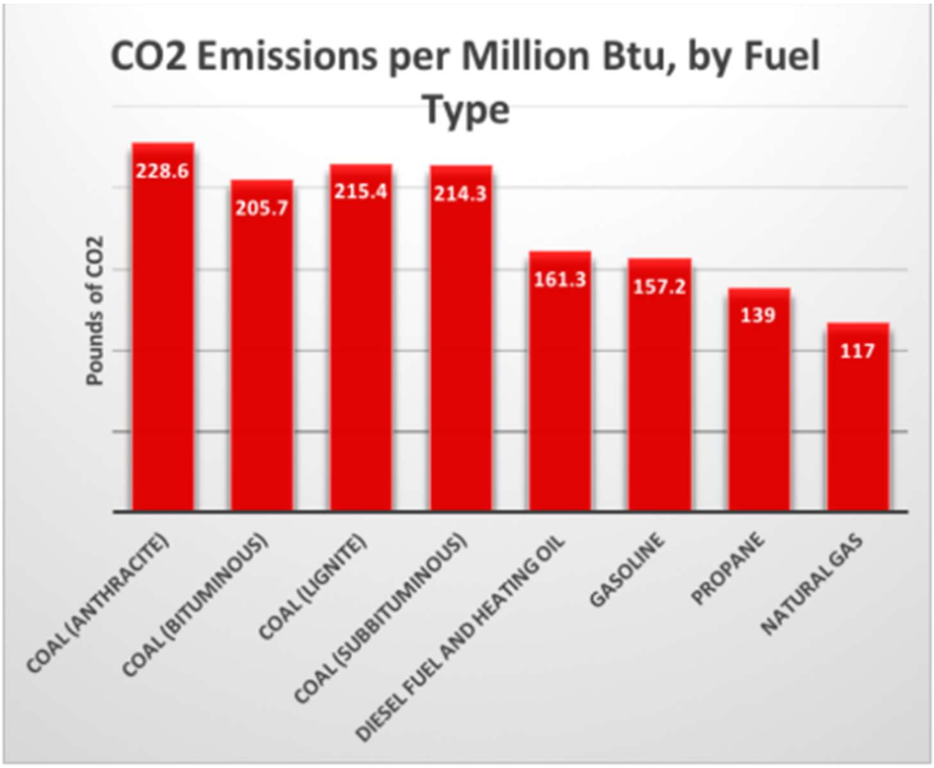
2.1.2 Carbon Tax

A Carbon tax is a fee imposed on the burning of carbon-based fuels, such as coal, oil and gas, with the aim to incentive population to switch to clean energy, as it would turn more economically rewarding to move to non-carbon fuels alongside being more efficient. A fee is applied according to the proportion of heat that each fuel releases into the atmosphere when used. This tax can be described as a Pigovian tax, which means a tax created to penalize activities or sectors in the market that generate negative externalities. In other words, it is a tax that allows the emitters of carbon-based fuels to pay the social costs that is attached to their activities. One of the main issues that this tax faces is its unilaterality; it is not applied according to an international plan, and it is

[13] Ec.europa.eu, https://ec.europa.eu/clima/policies/ets_en

not managed by an international authority and this leads to have the tax been managed individually by the different countries. Some countries have applied it effectively, but not all of them, and the individual action makes the positive results less effective, as they don't influence the overall GHG emissions as much as they could if the tax was applied globally.

In the following graph (graph 4) it can be see the amount of carbon emissions ranked by fuel type.



Graph 4. CO2 emissions by fuel type. Source: Carbon Tax Center[14]

Such policies were also promoted with the Kyoto Protocol, in particular three flexibility mechanisms were established in order to reduce emissions in a more cost effectively way. These mechanisms are: emission trading, joint implementation and the clean development mechanism. All the countries involved need to monitor and record their emissions to assure compliance with the targets chosen in the protocol. Furthermore, some Annex I countries, in particular those which had livestock that counts for a significant amount of their emissions, started to direct public resources into research to

[14] Carbon Tax Center: https://www.carbontax.org/whats-a-carbon-tax/

develop technologies to reduce CH4 emissions in ruminants and to subsidize the capture and burning of CH4 emissions from manure storage facilities. While a tax that directly targets CH4 emissions from livestock, some countries have tried in the past to implement it, such as the USA, Denmark, New Zealand and Ireland, however the proposals were met with strong opposition. Always Annex I countries, developed a emission trading system that allowed the development of offset markets to trade emissions allowances, however, the emissions reduction projects mainly focus on manure management and no other aspects of livestock, such as enteric fermentation, which causes the majority of emissions. Those emissions have not been taken into consideration so far as they result difficult to monitor.

2.2 Consumption side and production side

To reduce livestock's impact on climate change, there are two points of view from which to address the issue. From the consumer side it means reducing the levels of consumption of the products while from the production side, it includes all the livestock management that goes behind the production.

2.2.1 Production side

By addressing the production it would also help carry social and economic benefits to disadvantaged livestock producers in developing countries. However, the main problem when covering the production system is the feed and land management for ruminants. While biomass appropriation (potential productivity of ecosystems appropriated by humans), which usually results in ruminants production, can actually increase biodiversity and ecosystem productivity if done properly, this is not the case for the "as-is" situation. Currently, ruminants require a lot of resources and the low feed conversion rates (the amount of feed it takes to grow a kilogram of meat) alongside their long reproduction intervals, leads to the necessity of expensive and polluting maintenance of the animals. As previously mentioned, switching to monogastric meat production would mean lower emission intensity, lower phytomass appropriation (total amount of living organic matter) and reactive nitrogen.

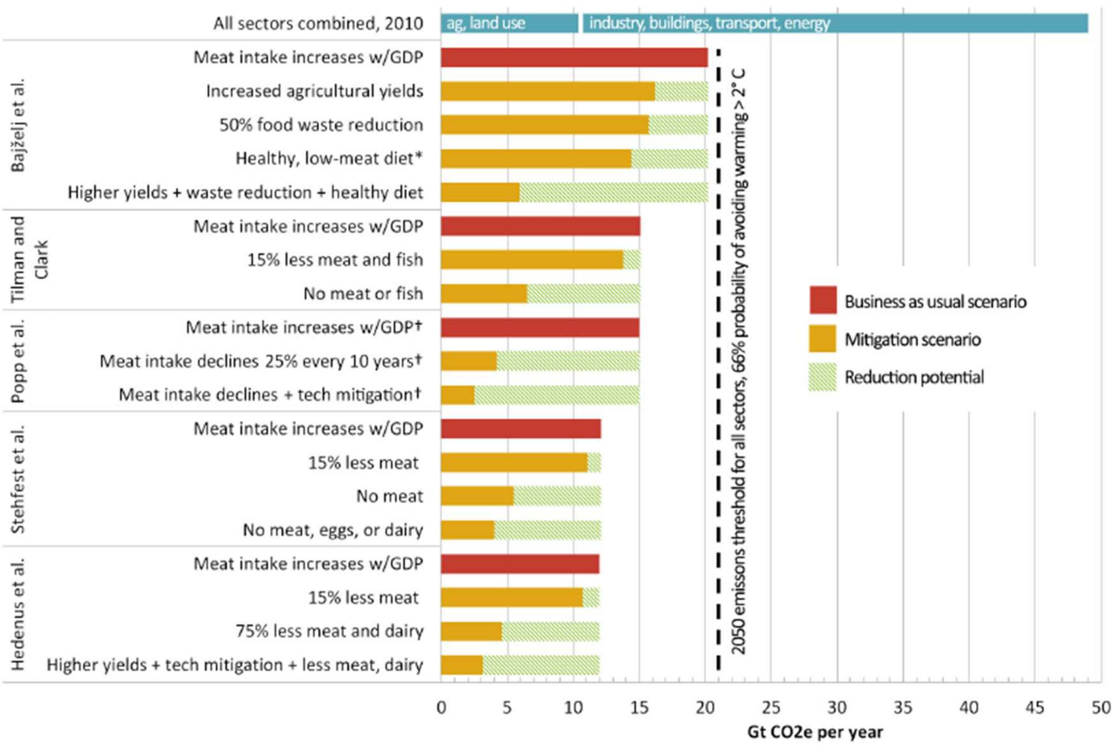
An increase in production, comes from an increase in demand and resource scarcity and those three have a mean to result in a reduction in phytomass appropriation per unit of product and emission intensity. With an application of science and advanced technology that makes the crop production more efficient, as it results in productivity increase and not area expansion, the impact of livestock on climate also diminishes, as livestock heavily relies on products coming from arable land. By closing these gaps between agriculture and livestock production, particularly present in developing countries the environmental impact of livestock would decrease significantly. However this increase in monogastric livestock production should be achieved in a responsible and efficient way, by reducing deforestation with an intensification of production, by enforcing area protection and certification of origin. A more responsible intensification can be met with incentives or with the possibility of marketing the avoided greenhouse gas emissions.

2.2.2 Consumption side

From the consumption side, all of these measures are destined to affect countries that are already below the average consumption of meat and that, according to regular dietary consumption, should actually increase their intake of meat products. With a public policy, there should be a reorientation of consumptions patterns, however, addressing dietary patterns is seen as a very personal choice, regardless of being helpful it may slow down the positive impact of more indirect actions (acting on the production side is seen as a more bearable action, while acting on dietary preferences is seen as too personal of a choice). Up till now there has not been a policy that addressed directly the impact of livestock on the environment, but more on water pollutions and odour issues, but the negative externalities could be corrected through regulations and market-based instruments, and these new directives could alter prices to showcase the social value of resources and emissions.

2.3 Possible methods and models to reduce GHG emissions

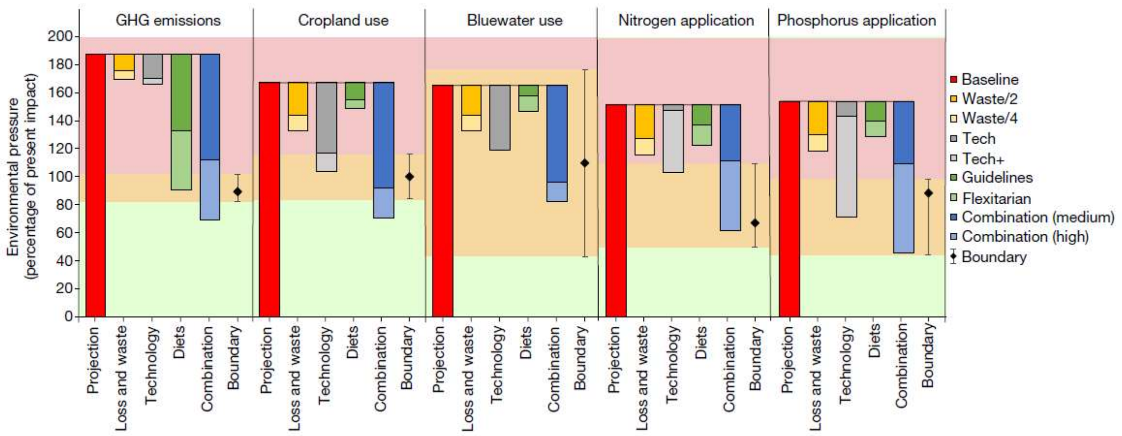
The previous actions to reduce greenhouse gases emissions, as it can be seen above, have always been heavily focused on carbon-based fuels, with no mention of livestock and its impact on climate change. Why livestock has such a big impact on climate change has already been discussed, but how to reduce its effects or how to reduce its production has still to be talked about. The easiest option, when thinking to reduce the presence of animal-based products in the market is to eat less of them. However, this action is not as easy as it sounds. For starters, livestock represents the main source of food for some developing countries, where they cannot afford richer diets that expands in other foods, such as cereals and vegetables, or at least they cannot afford it to an extend that is significant to substitute animal-based products with plant-based products. To further proof how little are the chances of changing a population mindset to switch to a plant-based diet, the Food and Agriculture Organization confirms that the consumption of meat and dairy is destined to grow with the increase in GPD and population growth. As can be seen in graph 5 below, in which five different studies have been compared, the potential of mitigating climate change throughout an action to limit or at least control all the activities related to livestock are quite high. The red bars represent the agriculture-related emissions by 2050 if there were no changes in that sector, the orange bars instead, represent the emissions if dietary changes and better food waste management were applied. At last, the green bars represent the potential in reduction of each scenario.



Graph 5. 2050 agriculture-related emissions scenarios. Source: (Kim et al., 2015)

According to these studies (Kim et al., 2015), which based their calculations on the FAO statement, livestock is responsible for 14.5 percent of the overall GHGs emissions, if a significant change in the dietary habits would happen by 2050, by reducing the intake of meat, dairy and eggs, the emissions related to the agriculture sector would reduce of an amount between 55 to 72 percent. According to Bajželj and the other authors of the researches used above to reach these numbers in graph 13, it is required a 31 percent reduction in global animal product intake, with a greater reduction in the countries where the intake is higher (Kim et al., 2015). An example would be Europe, as it would need to face a reduction of 64 percent of the intake that it is currently taking place, especially for red meat and poultry. Moreover, not only the reduction of animal products intake is essential, but also the food waste management system needs to be transformed. Instead of throwing waste in landfills, food waste should be recovered by transforming it into animal feed, for industrial purposes or for composting and energy generation. A third of the food is currently estimated to be lost before it reaches the market or is wasted in households (Kim et al., 2015). This would lead to a reduction in emissions of 4.5 Gt. (gigatons) by 2050, which is more than the reduction that could be achieved with technological mitigation, which would reach 1.5 Gt at worst and 4 Gt at best (Kim et al., 2015). The difference between the impact the food waste reduction and animal products reduction, is explained by the fact that a significantly higher amount of vegetables, fruits and cereals are wasted rather than animal products.

The following analysis will evaluate the impact of reducing food waste up to a one half, as the value line pledged by the Sustainable Development Goals for 2030. The analysis will also include the results coming from a reduction of 75% of food waste, which is estimated to be the maximum theoretically avoidable value (Springmann et al. 2018). According to this analysis reducing food loss and waste would reduce environmental pressure by 6-16% compared to the baseline projection for 2050 and it would increase to 9-24% if reduction would be of 75% (Springmann et al. 2018). The impact is bigger on emissions caused by stable crops and vegetables than livestock itself, but as mentioned before, the majority of land use for crops can be traced back to livestock production. Technological improvements also increase the efficiency in food management and reduces the environmental impact per unit of food produced as can be seen in graph 6. The projections pictured, are without dedicated mitigation measures and are presented as percentages of present impacts. All the changes are shown as reduction from the baseline projections for the different environmental domains. The loss and food waste are represented under two different colours, *waste/2* for the reduction by half and *waste/4* for the reduction of 75%. *Tech* stands for medium-ambition technological changes, while *Tech +* stands for more ambitious changes in the tech department. *Guidelines* shows diet scenarios following the global dietary guidelines, *Flexitarian* instead, represents more plant-based diets. *Combination (medium)* includes all measures with a medium ambition, while *Combination (high)* stands for all measures with high ambition, also including a positive socioeconomical pathway with a higher income and lower population growth. At last, *Boundary* stands for mean planetary-boundary values, each associated with uncertainty intervals, highlighted by colour (green, orange and red). The action includes an increase in agricultural yields, which would reduce the demand of additional cropland; rebalancing fertilizer application between the regions where it is overapplied and underapplied; increasing nitrogen-use efficiency and phosphorus recycling; improving water management and finally applying agricultural mitigation options, such as changes in irrigation, cropping and fertilization, manure management, feed conversion and feed additives to reduce enteric fermentation in livestock.



Graph 6. Impacts of reduction in food loss and waste, technological change and dietary changes on global environmental pressures in 2050. Source: (Springmann et al. 2018)

The implementation of such measures, would reduce environmental pressures of the food system up to 30% from the 2050 baseline *Combination (medium)* projection and up to 54% with the *Combination (high)* scenario (Springmann et al. 2018). As it can be seen from graph 6, the higher-end estimates refers more to stable-crop dominated indicators, as a lot of improvement can be done in this area, while the lower-end estimates are more evident in the GHGs emissions coming from livestock, as most of these emissions come from the animal itself, and cannot be reduced through currently available mitigating activities. Changing the dietary habits towards a diet based more on fruits, vegetables, legumes and nuts, and decrease consumption of red meat first, and other meats second, could reduce GHGs emissions and other environmental impacts from 29% up to 56% depending on the scenario chosen (medium or high combination). In fact, between all the actions mentioned, changing dietary consumption is the action with the highest effect on GHGs emissions from livestock.

2.3.1. GLEAM

Another model to gather information about livestock and its link with climate change that differs from the previously mentioned FAO and IPCC is GLEAM. GLEAM stands for Global Livestock Environmental Assessment Model and it was developed to improve the understanding of livestock GHG emissions along supply chains, to identify and prioritize areas of intervention to lower sector emissions (Gerber et al., 2013).

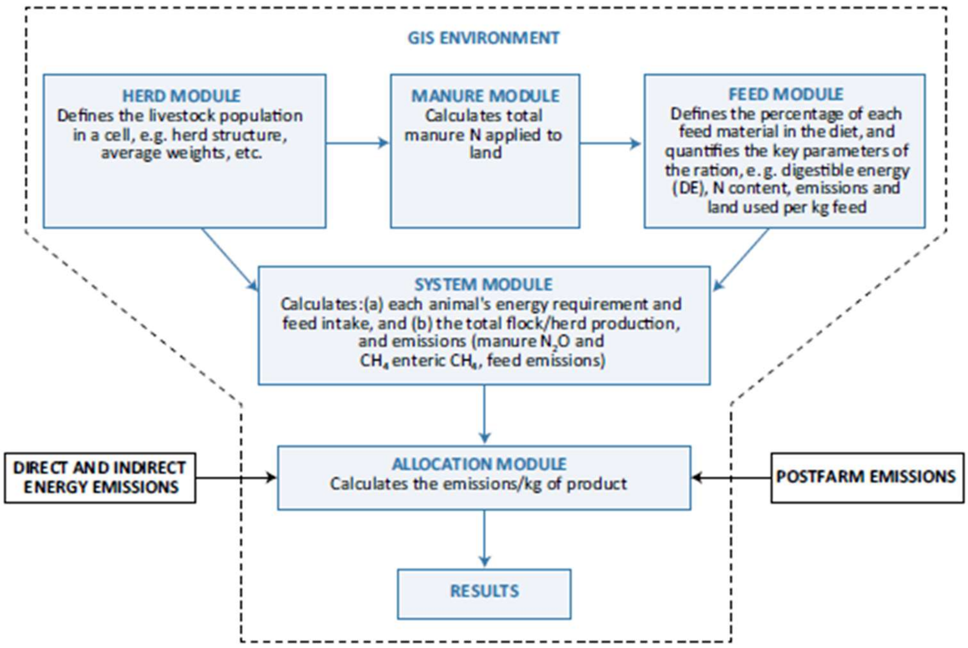


Figure 2. Overview of the GLEAM modules and computation flows. Source: (Gerber et al., 2013)

GLEAM is built to represent the main elements of livestock supply chain as it can be seen in the figure 2 (above). These modules are the following: the herd module, the feed module, the manure module, the system module, and the allocating module. The herd module attributes the animals to different farming systems, determines the herd structure, which includes the number of animals in each cohort and how they move between cohorts and the characteristics of the animals in each cohort, such as weight and growth rate. Furthermore, in this module feed parameters are calculated, for example the nutritional content per kg of feed ration. This structure and the characteristics of the animals will later be used in the system module to attribute the energy requirements per animal type and the amount of products produced each year (i.e. meat, eggs and milk). In the system module, it will also be calculated the total annual production and the amount of emissions which comes from manure, enteric fermentation, and feed production. In the amount of energy used it is included the on-farm energy use, the construction of farm buildings and manufacture of equipment. The information will also be used in the manure module to gather estimations of manure production. The allocation module is where all the farmgate emissions are allocated to co-products and services. The post-farm emissions are kept separate and added just at the end to gather an overview of the overall emissions. The emissions considered come from all the main sources of the livestock's supply chain, aside from the emissions with a small marginal impact. Another omission involves the changes in the soil and vegetation carbon stocks, labour force and provisions of services and assistance of stakeholders along the chain as the data available is not reliable enough or it has its limitations to contribute truthfully to the total emissions.

Types of emissions considered in the GLEAM:

- Land-use change emissions: this is a difficult process to address, as it comprehends both direct and indirect drivers, from grazing to secondary forest re-growth. However, the main driver regarding the quantity of GHG emissions is deforestation. In GLEAM the only land-use change considered is, in fact, the change from forest to arable land or to pasture. In this calculation it was only considered, with regards of feed crops, soybeans in Brazil and Argentina, as for the time frame considered in this process, it was only in Latin America that the production of feed crops could be directly related to a decrease in the forest area. Within Latin America in this period, 90% of soybean production happened between Brazil and Argentina (Gerber et al., 2013).

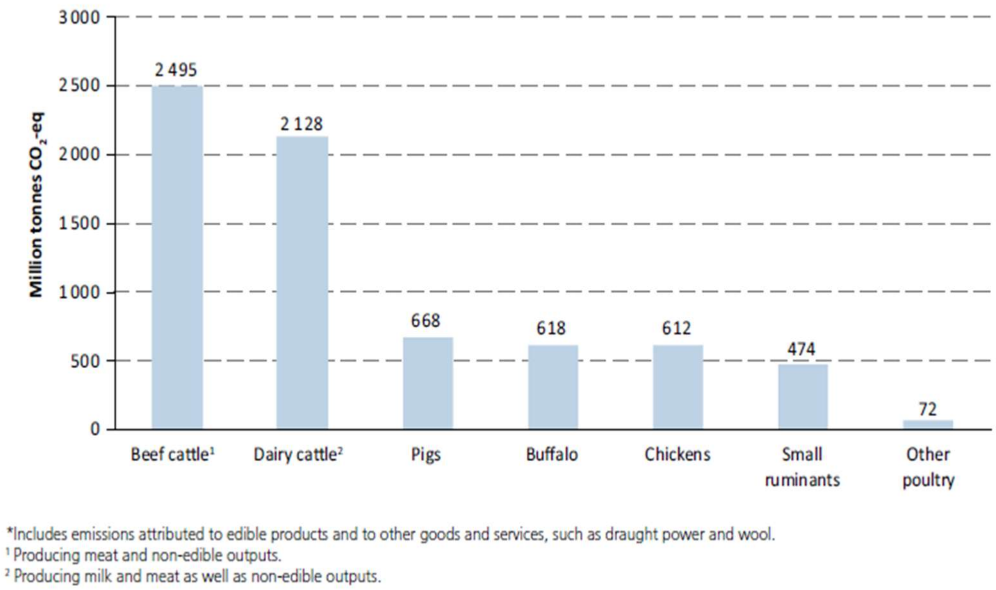
- Supply chains: 14.000 discrete supply chains are included in the calculations of the GLEAM, and they represent a combination of commodities, farming systems, countries, and agro-ecological zones. These supply chains are later decomposed into smaller production units, called pixels or grid cells. There are 11 commodities dividing according to meat and milk. Ruminants are differentiated into mixed and grazing systems, pigs into backyard, intermediate and industrial systems and chickens into backyard, layers, and broilers.
- Allocation: used to allocate the GHG emissions to other fundamental relationships when physical relationships cannot be established. Usually it is used the economic allocation, by assigning the emissions to each product according to its share of the product's combined economic value. However, the economic value is not the only method of allocation, as it is also used the weight and the protein content. Slaughter by-products, such as blood and skin, have not any emission allocated as they are characterized by high temporal and spatial variability.
- Data: the data used by GLEAM to compute the emissions that can be attributed to livestock is geo-referenced. The data gathered for production and productivity were collected at different levels of aggregation, such as country level, agro-ecological zones and production systems or it could come from a combination of them. The number of livestock, pasture and feedstuff was gathered in the GIS grids form (a storage of data per location, which allows spatial heterogeneity into the model).

It needs to be clarified that given the extent of coverage that the uncertainty analysis has to do, as it is a global assessment, there is a degree of uncertainty regarding the results. However, some sensitivity analysis have been run, to limit the element of error in the final results.

Although the studies' results done by the GLEAM can be compared with several LCA studies (life cycle assessments, used to assess environmental impacts of the different stages of the life-cycle of a product or service), they are not necessarily equal as the methodologies that can be used are plenty, hence the comparison is not straightforward and it needs some adjustments to take into consideration the differences. Most of the differences can be regarded as differences in approaches and assumptions made, mainly with regards of feed consumptions and digestibility, animal weights and others.

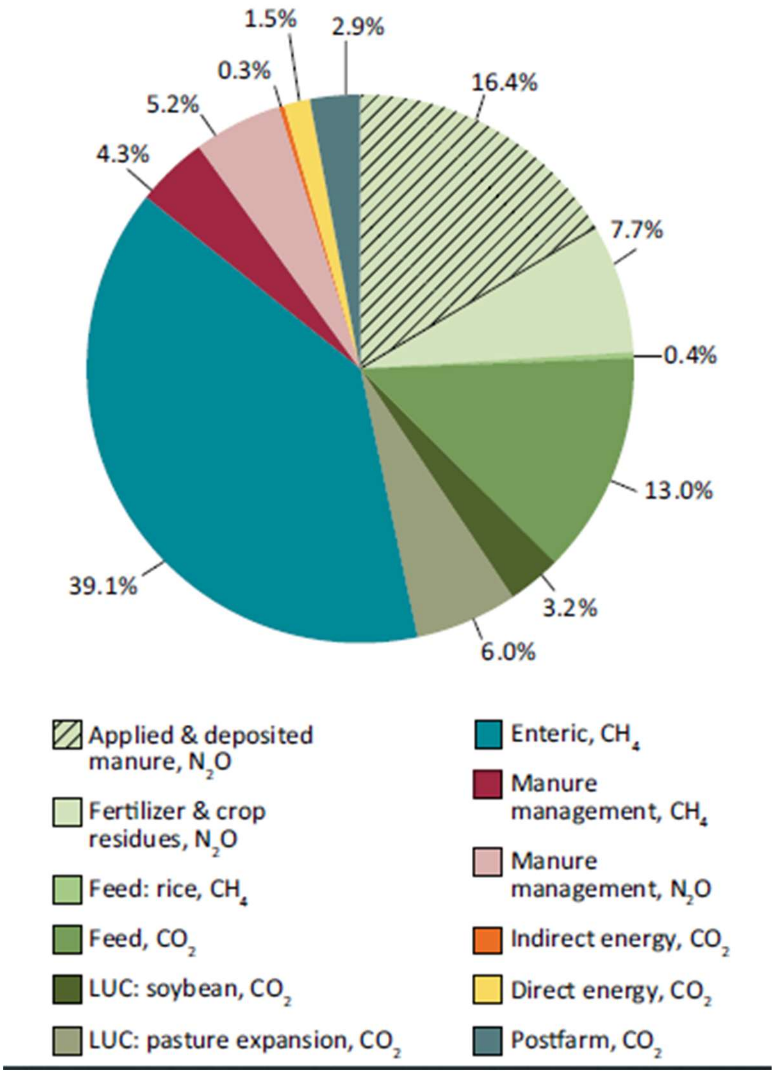
Emissions by species and commodities in GLEAM:

Cattle is the species that is the most responsible for the overall emissions, according to GLEAM, as its emissions represent 65 of the total sector emissions, around 4.6 gigatonnes of CO2-eq (graph 7).



Graph 7. Global estimates of emissions by species. Source: GLEAM

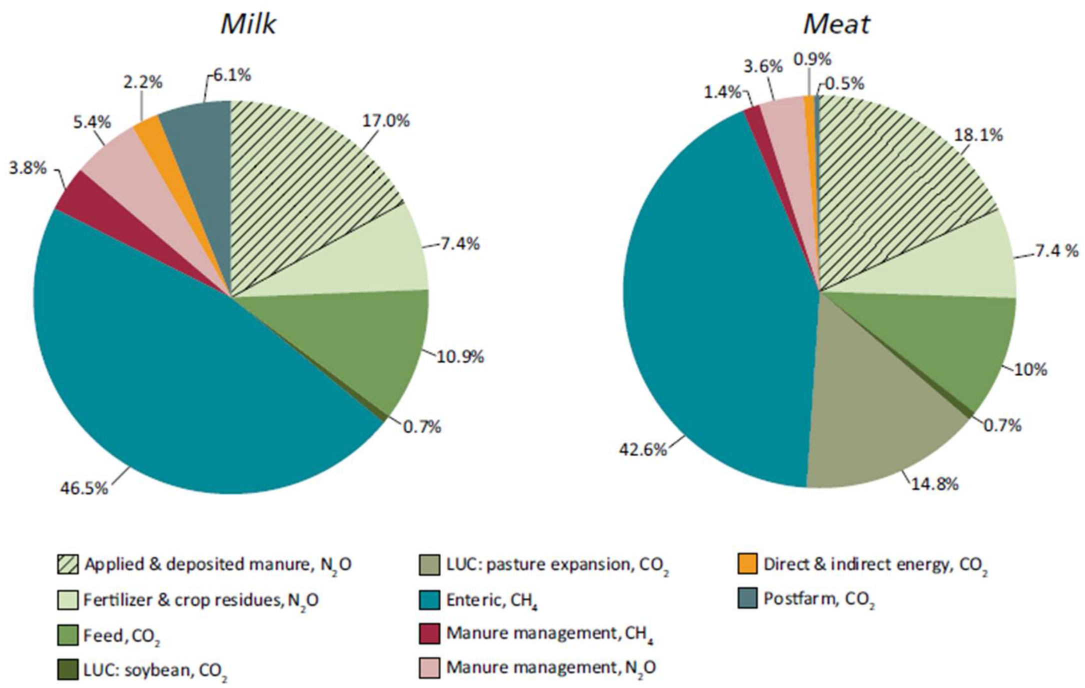
The emissions vary among producers, as there is a difference between the agro-ecological conditions, the practices followed by the farms and the supply-chain management. 45 percent of the sector emissions are traced back to the production, processing and transport of feed (Gerber et al., 2013). Nearly half of the emissions come from the fertilizers, a quarter from land-use change as it can be seen in graph 8 below.



Graph 8. Global emissions from livestock supply chains by category of emissions. Source: GLEAM

CATTLE

As mentioned previously cattle represents 65 percent of the livestock emissions, making it the main source of GHG between the different species (Gerber et al., 2013). Cattle comprehends both beef production and milk production, but in the emissions' calculation it is kept into consideration also the products and the services related to this species, such as manure used as fuel. These last activities might not sound too relevant in developed countries, but they represent around 25 percent of the emissions in countries such as South Asia and Sub-Saharan Africa. Cattle main source of emissions comes from enteric fermentation, that equals 46 percent of the emissions from the dairy supply chain and 43 of the beef supply chain (Gerber et al., 2013). Following enteric fermentation, at the second place for quantity of emissions there is feed fertilization, representing 36 percent of beef and milk emissions (Gerber et al., 2013). This percentage does not take into consideration pasture expansion (for beef production system) which would lead the percentage to more than half for specialized beef systems. There is also a difference between the emissions from dairy herds and specialized beef herds, as the latter have higher emissions. This is because the emissions from dairy herds are divided between the milk and the beef production, as usually these herds produce both. The difference can also be explained in the intensity of the breeding system, as the animals have a different feed quality and herd management.

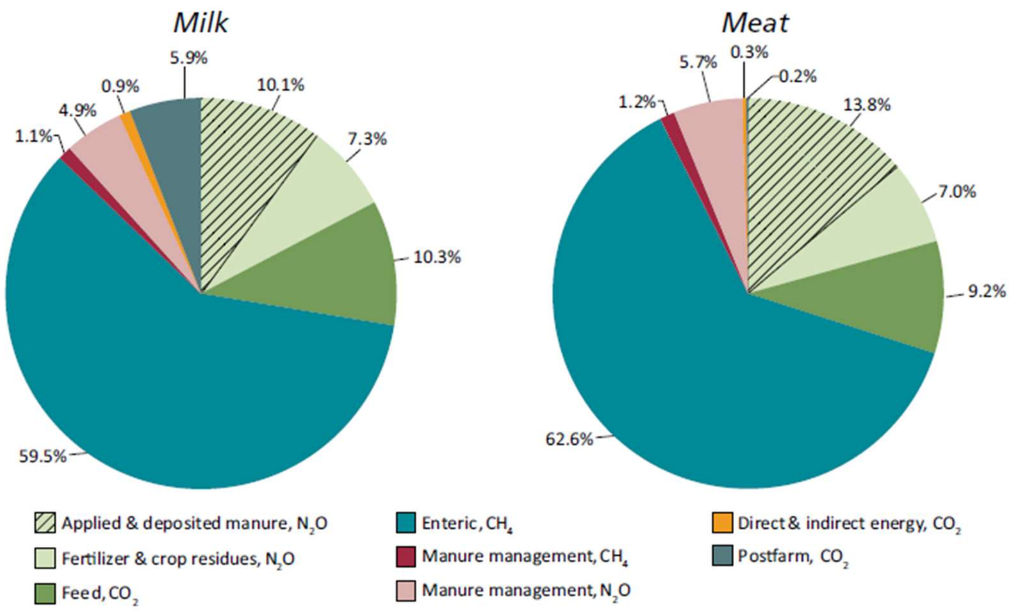


Graph 9. Global emissions from cattle milk and beef supply chain, by category of emissions. Source: GLEAM

Regarding beef production the sources of emissions are low feed digestibility, slow growth rates of the animals and a longer life of the animal due to high age at slaughter as much as pasture expansion into the forest areas, especially in Latin America and the Caribbean as mentioned above. For milk production, however, the emission intensity seems to be lower in industrialized regions as better feeding and nutrition help reduce methane and manure-related emissions. The main reason behind this being that in developing countries feed production and processing and manure are responsible for a way higher amount of emissions.

BUFFALO

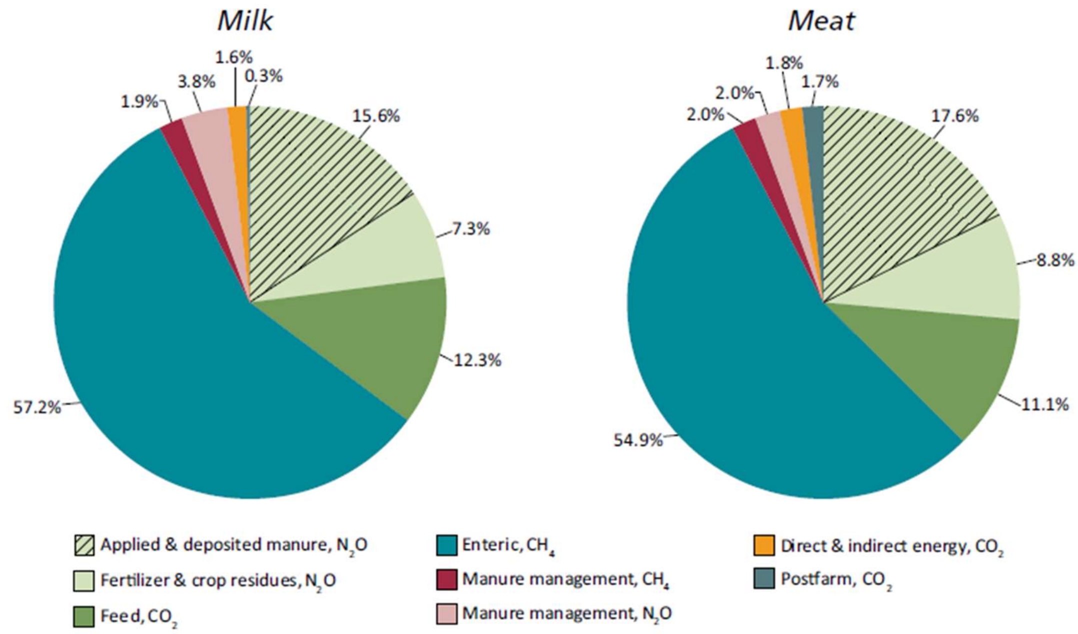
The emissions from the buffalo represents around 9 percent of the sector's emissions (Gerber et al., 2013), including milk production, meat production and other goods and services related to this species. As for cattle, the majority of the emissions come from enteric fermentation (around 60 percent of the total emissions from buffalos and it is higher than cattle which is 45 percent, the difference given by the lower digestibility of the feed), which is followed by feed fertilization. However, for buffalo the emissions regarding land-use change are close to zero, as this species is not present where pastures are expanding and the quantity of soybean in their feed is limited. The production is mainly based in South-East Asia, where 90 percent of global buffalo meat and 70 percent of buffalo milk is produced (Gerber et al., 2013), but they are also present in North Africa and the near East. The emission intensity being higher in South-East Asia given the poor feed resources and the low reproductive efficiency.



Graph 10. Global emissions from buffalo milk and meat supply chains, by category of emissions. Source: GLEAM

SMALL RUMINANTS

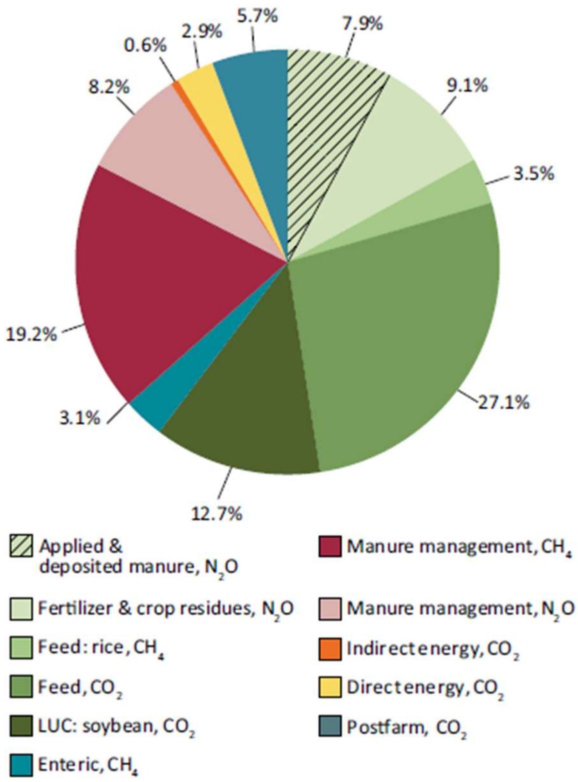
When talking of small ruminants, goats and sheep are considered as the main species for this category and they represent around 6.5 percent of the sector's emissions (Gerber et al., 2013). The main difference between the two is that the milk production from goat has lower emissions thanks to the composition of the milk itself (fat and protein corrected milk). 55 percent of small ruminants' emissions are from enteric fermentation and 35 percent from feed production (Gerber et al., 2013). Compared with the other species, it is also important to stress that post-harvest energy consumption and manure emissions are lower given the necessity of less processing and the fact that manure is mainly deposited on pasture. Aside from some exceptions, the production is more important in less affluent regions. One crucial aspect of small ruminants is that aside from producing milk and meat they also produce non-edible products, such as wool, cashmere and mohair (natural fibre). This means that the emissions must be divided between edible products and non-edible products, and where the latter have a high economic value it increases the shift of emissions towards it.



Graph 11. Global emissions from small ruminants' milk and meat supply chains, by category of emissions. Source: GLEAM

PIG

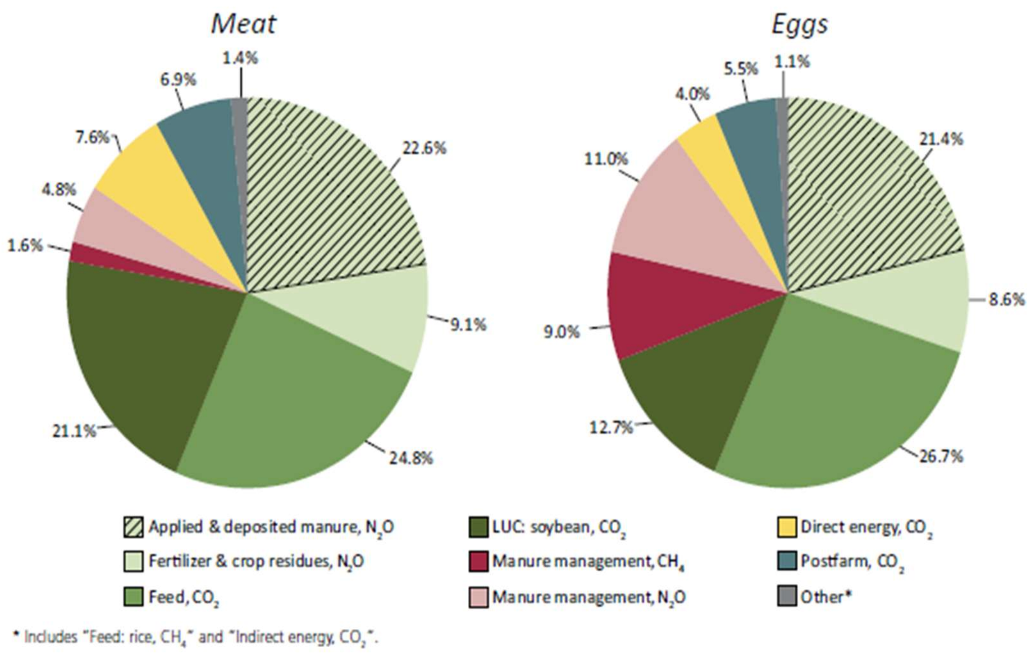
The production of pig products accounts for 9 percent of the global sector emissions, to which the main contributor is feed production, which is responsible for 48 percent of the emissions of this species, 12.7 percent to land-use change, given the high intake of soybean and 27 to the production of fertilizers, use of machinery and transport of feed (Gerber et al., 2013). However, at the second place for emissions, after feed production stands manure management (both its storage and its processing) that accounts for 27.4 percent of the total emissions, and most of these emissions are in form of CH4 (methane) and the rest in N2O (nitrogen). Post-farm emissions for processing and transport alongside the energy used for production are also relevant elements that contribute to the total emissions. With regards to the production systems (industrial, intermediate and backyard) there is not much difference in the amount of emissions between the three systems, even though the industrial system still ranks at the first place and the backyard system to the last if compared with one another. However, the backyard system is still responsible for the highest emissions in the manure given the volatile solids and excretions, but those emissions are toned down by the very low feed production's emissions. In the intermediate system there is a higher intensity of emissions explained by the poor feed conversion and the high quantity of rice in the feed ration, which has a higher production of CH4 if compared with other cereals, also to consider is the manure storage. The population of pigs is mainly located in Europe, East-Asia, and Americas, mostly for religious reasons, this implies that the productions happens near the consumption areas, importing only feed.



Graph 12. Global emissions from pig supply chains, by category of emissions. Source: GLEAM

CHICKEN

Chicken represents around 8 percent of the sector's emissions. The main source of emissions for this species is feed production in all its forms, meaning including fertilization, use of machinery and transport. The feed production is responsible for around 57 percent of emissions from both meat and eggs, with an addiction for the expansion of soybean cultivation of 21.1 percent and 12.7 percent for chicken and eggs respectively (Gerber et al., 2013). Manure is also relevant in the eggs production as it represents 20 percent of total emissions, rather than the 6 percent for meat, this difference comes from the difference in the approach used in the production, which is the liquid system with long-term pit storage for eggs. As mentioned before the liquid system produces way more emissions than a production in dry and aerobic conditions. For the production of chicken and its by-products there are three different systems: backyard system and industrial system that expands between production of both meat and eggs, and broilers, which produce only meat. The most commonly used systems for meat and eggs, which are respectively industrial broilers (90 percent of meat production) and intensively-managed laying hens (85 percent of egg production) are also the two system which produces the lowest amount of emissions. Backyard production, on the other hand, is the most intensive one, emission wise, however, it represents only 10 percent of GHG emissions and that is mainly because it happens in small units and the animals grow at a very slow pace. Moreover, this system has poorer feed conversion ratios as the quality of food is low, animals spend time scavenging for feed, and the backyard system has a higher number of unproductive animals, due to the higher death rates and low fertility. There is little to no difference in the quantity of emissions in the three top countries (Latin America and the Caribbean, North America and Southeast Asia) where the chicken and eggs production occurs, due to the high level of standardization of technologies and production systems.



Graph 13. Global emissions from chicken meat and egg supply chains, by category of emissions. Source: GLEAM

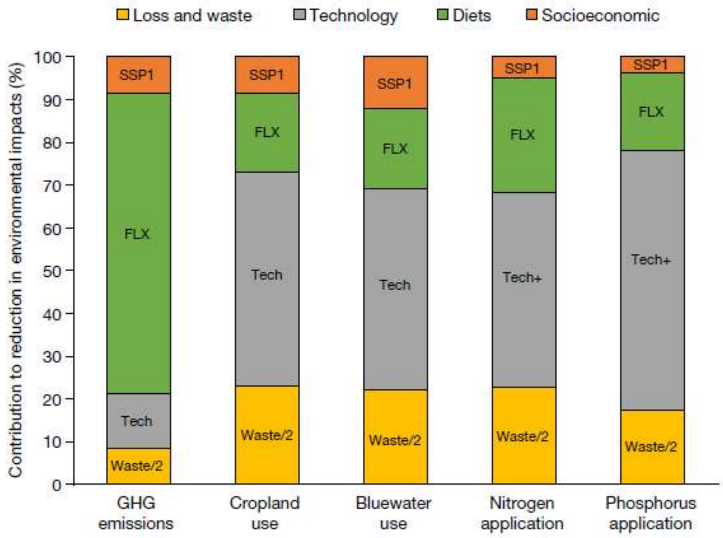
2.3.2 PLANETARY OPTION SPACE

When speaking about planetary boundaries, it means a safe operating space for humanity. The planetary boundaries define a space around the present values for most environmental domains, with a mean slightly below for food-related GHGs emissions compared to current values and slightly above current values for bluewater use and substantially low values for nitrogen and phosphorus application. With the current level of increase in population and income change that will inevitably happen in the future, followed by changes in food consumptions and production, all mean values would be crossed. The environmental impact of food related GHGs emissions would exceed the boundaries set by the planetary option space by 110%, 70% for cropland use, 50% for bluewater use, 125% for nitrogen application and finally 75% for phosphorus application (Springmann et al. 2018). To remain below planetary boundaries a combination between medium intensity and high intensity should be followed. The different combination are shown in table 8 below, in which colours and numbers indicate combinations that are below the lower bound of the planetary-boundary range (dark green, 1); below the mean value, but above the minimum value (light green,2); above the mean value by below the maximum (orange, 3); and above the maximum value (red, 4).

Diet scenario	Tech scenario	Loss and waste scenario	GHG emissions			Cropland use			Bluewater use			Nitrogen application			Phosphorus application		
			SSP2	SSP1	SSP3	SSP2	SSP1	SSP3	SSP2	SSP1	SSP3	SSP2	SSP1	SSP3	SSP2	SSP1	SSP3
Baseline	Baseline	Baseline	4	4	4	4	4	4	3	3	3	4	4	4	4	4	4
		Waste/2	4	4	4	4	4	4	3	3	3	4	4	4	4	4	4
		Waste/4	4	4	4	4	4	4	3	3	3	4	4	4	4	4	4
	Tech	Baseline	4	4	4	4	4	4	3	3	3	4	4	4	4	4	4
		Waste/2	4	4	4	3	3	3	2	2	2	4	4	4	4	4	4
		Waste/4	4	4	4	2	2	2	2	2	2	4	4	4	4	4	4
	Tech+	Baseline	4	4	4	3	3	3	3	3	3	3	3	3	2	2	2
		Waste/2	4	4	4	2	2	2	2	2	2	3	3	3	2	2	2
		Waste/4	4	4	4	1	1	1	2	2	2	3	3	3	2	2	2
Guidelines	Baseline	Baseline	4	4	4	4	4	4	3	3	3	4	4	4	4	4	4
		Waste/2	4	4	4	4	4	4	3	3	3	4	4	4	4	4	4
		Waste/4	4	4	4	4	3	4	3	3	3	3	3	3	4	4	4
	Tech	Baseline	4	4	4	3	3	3	3	2	3	4	4	4	4	4	4
		Waste/2	4	4	4	2	2	2	2	2	2	4	3	4	4	4	4
		Waste/4	4	4	4	2	1	2	2	2	2	3	3	3	4	3	4
	Tech+	Baseline	4	4	4	2	2	2	3	2	3	3	3	3	2	2	2
		Waste/2	4	4	4	1	1	1	2	2	2	3	3	3	2	2	2
		Waste/4	4	3	4	1	1	1	2	2	2	3	3	3	2	2	2
Flexitarian	Baseline	Baseline	3	2	3	4	4	4	3	3	3	4	4	4	4	4	4
		Waste/2	1	1	2	4	4	4	3	3	3	3	3	3	4	4	4
		Waste/4	1	1	1	4	3	4	3	2	3	3	3	3	3	3	3
	Tech	Baseline	2	1	2	3	3	3	2	2	3	4	4	4	4	4	4
		Waste/2	1	1	1	2	2	2	2	2	2	3	3	3	4	4	4
		Waste/4	1	1	1	1	1	2	2	2	2	3	3	3	3	2	3
	Tech+	Baseline	1	1	2	2	2	2	2	2	3	3	3	3	2	2	2
		Waste/2	1	1	1	1	1	1	2	2	2	3	2	3	2	2	2
		Waste/4	1	1	1	1	1	1	2	2	2	2	2	2	2	1	2

Table 8. Planetary Option Space. Source: (Springmann et al. 2018).

Combining these options would lead to the adoption of different measures of technological change for each environmental domain, coupled together with dietary changes towards a more plant-based diet, reduction in food loss and an positive socioeconomic development pathway, as seen in graph 14.



Graph 14. Combination and relative contributions of mitigating measures that simultaneously reduce environmental impacts below the mean values of the planetary-boundary range. SSP1 = optimistic socioeconomic pathway with higher incomes and lower population growth; FLX = plant-based flexitarian diets; Tech/Tech + = technological improvements, respectively of medium and high ambition; Waste/2 = food waste reduced in half. Source: (Springmann et al. 2018).

2.3.3 TECHNOLOGY TAKE

- Agricultural yields, that would decrease the demand of additional cropland.
- Rebalancing the quantity of fertilizers between the countries which overapply it and the ones the underapply it.
- Increasing the efficiency in nitrogen use and phosphorus recycling (helps reducing both demand of nitrogen and phosphorus inputs).
- Improving water management, storage capacity and including other agricultural mitigation options, such as changes in irrigation and changes in manure management.

If all of these implementations were applied, the environmental pressure on the food system would decrease between 3 and 30 percent (Springmann et al. 2018). The higher end of the percentage represents the stable-crop dominated indicators, such as cropland and nitrogen application, for which the improvements mentioned above are highly effective. The lower end instead, is related to livestock emissions, meaning all the emissions directly attributed to the animal itself, which cannot be reduced through the application of the mitigation options mentioned.

2.3.4 INCENTIVE POLICY ON SECTORAL EMISSIONS

The first policy that will be discussed is an incentive policy based on sectoral emissions, as it proves to be more administratively feasible than a policy at the producer level emissions. The following policy will show the impact of a carbon tax and an emission trading scheme based on methane emissions per unit of commodity. As mentioned before diminishing CH_4 emissions, coming from enteric fermentation, can be done through an improvement of feed quality, by changing its components with less damaging once, and by increasing the quantity of feed per head, which would increase the proportion of feed energy that is converted into animal products rather than animal maintenance. Another option involving CH_4 mitigation, regards digesters, which are machines designed to capture methane and transform it into energy. As mentioned in the previous chapter, animal products are the cause of a huge amount of emissions, and substituting them with other products that do either not involve livestock or animals that have a lower impact on climate change can greatly diminish the emissions coming from this sector. An example is set by switching beef (20.3 tonnes of CO_2-eq CH_4 are emitted per ton of beef) with pork (1.1 t) or chicken (0.2 t), which would reduce methane emissions by 94% and 99% respectively (Key and Tallard, 2009). The main issue with building and applying incentive-based schemes to reduce livestock's emissions comes from the hardship of measuring and monitoring emissions as well as verifying compliance and enforcing the policy. Plus the costs coming from the transactions necessary to apply those policies are quite high, as they include filing paperwork, legal advice and registering emissions, which make them unprofitable for most producers. This is another reason why these policies, to be more effective should address aggregate emissions, which means at a national or sectoral level instead of farm-level emissions, as it would break down both administrative costs and producers transactions. Furthermore, in aggregate emissions, enteric fermentation is included thanks to the IPCC methods.

2.3.5 4 ACTS TO REDUCE EMISSIONS

- Commodity tax: the commodity tax is a policy which reduces emissions by altering the relative price of goods, which induces customers and producers to shift towards products with lower associated emissions.

- Carbon tax: a carbon tax on output based on average emissions per unit in the country where the good is produced. This tax would induce both consumers and producers to switch from higher emissions commodities to once with lower emissions, which means from beef, sheep meat to chicken and pork. It would also cause a shift in the location of livestock, from regions with intense emissions per ton, to the once with a lower intensity. The issue with this specific tax would be that the production would shift to non-taxed regions, causing emissions leakage, due to costs of transport and it would diminish the efficiency and purpose of the tax. However, this problem can be solved by taxing domestically consumed goods, including both imported and domestically produced goods, based on their embodied emissions. While this option seems to solve it all, it also brings to surface another issue, which is the difficulty to measure the emissions coming from imports. Another option to avoid emissions leakage, would be by taxing only based on the average embodied emissions for the commodity category, excluding where the good came from. In this way, products like beef could be taxed more and that wouldn't influence countries' competitiveness, as domestic and imported goods would be taxed the same way. When talking about a sectoral approach, it becomes clear that there is the necessity of applying the policies in a "fair" way, in order to not disadvantage developing countries, and this would be done by adapting the costs of emissions and policy outcomes. In the most rural areas of these countries, livestock represents a huge source of not only nutrition, but also income, which means that policies should incentive economic development and reduce poverty.

- CDM projects: The Clean Development Mechanism allows countries which committed to the Kyoto Protocol, to implement emission reduction projects in developing countries. With these project Non-Annex 1 countries, which are not under any obligation under the UNFCCC to reduce their GHG emissions, can participate in the international efforts to reduce emissions, in particular CH4 emissions coming from livestock. These projects generate CER (Certified Emission Reduction) credits, which counts for the Kyoto Protocol emissions reduction targets. However, up till 2008, only 5% of the projects regarded livestock's emissions CIT, mainly because of the difficult process of certification of the project, as it has to be made sure that the emissions can be calculated and that the project will actually make a difference (Key and Tallard, 2009). Their complexity and expensiveness does not help the reduction of large-scale emissions from developing countries, furthermore these projects do not promote local environmental quality or development. After the Kyoto protocol some adjustments for the CDM projects have been brought up, such as: improving the "activity-based" CDM; creating a non-market mechanism which would allow to finance mitigation in developing countries without creating international offsets; and add sectoral approaches. Why is a sectoral approach so crucial? With a sectoral approach a government gets credits according to its efforts to reduce emissions. Developing countries, which apply specific mitigation techniques by measuring the emissions according to a sectoral baseline, then sell the reductions to an international carbon market. The governments who participate then gives the credits to industries and households that were more affected by the mitigation efforts. With a sectoral emission trading scheme the countries would be facing a target based on national emissions from a sector. In a proposal of this mechanism, called sectoral crediting mechanism (SCM) or "no-lose" target, non-Annex 1 countries would receive tradable permits if the emissions would be reduced after a specific target. If the target is respected, and emissions exceed it, there is no penalty incurred, plus participation to this trading scheme is not binding. While this absence of downsides to apply SCM should be met with support and willingness to participate, there is a disadvantage coming from it, which is the fact that an incentive to reduce emissions for the countries who choose not to participate does not exist. On the contrary, this scheme would induce these countries to increase production as a response to higher global product prices that comes from the trading scheme itself.

- "high-cap" sectoral emission trading scheme: where the main difference is that non-Annex 1 countries have to purchase emission permits in an international market if emissions are above their cap. The cap, however, is still set high enough that is rarely reached. This new view on the scheme, would create incentive for developing countries to participate as they would earn revenues from permits sales, indirectly guiding them towards lowering their emission to generate more sales. To work in the livestock sector, it should operate alongside an external emission trading market where producers and nations which do not relate to livestock buy permits from and sell permits to the livestock sector. Through this scheme the revenues are managed by the government, rather than the producers, which means that this mechanism needs to be enhanced with the help of national mitigation policies to incentive producers to reduce their emissions. Following, for purpose of simplicity, the mitigation policy will be represented by a carbon tax on livestock production based on average embodied emissions. The costs regarding the sectoral emission trading approach are quite low in the context of agricultural methane emissions, both at the administrative and the production transaction level. The emission reduction credits would be calculated through the IPCC guidelines, the monitoring would happen with the tracking of production levels in several production systems and it would allow developing countries to move towards emission limitation commitments within the framework of an international climate regime. Furthermore, it would guarantee to developing countries the access to large-scale climate projects and to build the required technical capacity and infrastructure, including the development of a national emission inventory.

2.3.6 THE IMAGE MODELING FRAMEWORK

The IMAGE model or Integrated Model to Assess the Global Environment, is a model framework built to explore the long term dynamics of global change as a function of drivers, like demographic and economic development, including also developments in the energy and agricultural system. Instead of focusing on all different aspects of this model, in the following paragraph, it will be explored the climate policy included in

IMAGE, which is the model FAIR. This model is used to calculate global emissions pathways that lead to a stabilization of the atmospheric greenhouse gas concentration. The environmental parameters are simulated at a 0.5 by 0.5° resolution by the ecosystem, crop and land-use models used in IMAGE (Stehfest et al., 2009). All the emissions considered (energy use, industry, land use, changes in land-use, crop and livestock systems) are calculated on the basis of the IPCC 2006. Something included in this model, that was not previously discussed, is the biosphere-atmosphere exchange of CO2 and feedbacks of climate and atmospheric CO2. Lastly, mean temperature change is firstly measured with the MAGICC model (an Atmosphere-Ocean model) and then translated via a pattern-scaling method to project climate change, with the same parameters as the other variables.

In the mitigation scenarios, a global emission pathway that complies with a 450 ppm CO2-eq will be used, with an allowance to overshoot up to a level of 510 ppm CO2-eq in the middle of 21st century. Using the FAIR model (through marginal abatement costs curves) to distribute the emission reductions required to achieve this global emission pathway across sectors, gases and world regions in a cost-optimal way for the climate policy cases. The emissions coming from the energy sector are derived from another model (TIMER) imposing different levels of emissions permits prices, resulting in an increasing of the market share for fuels with low carbon emissions, with a price driven increase in energy-efficiency. Marginal abatement cost curves for non-CO2 gases are based on the EMF-21 project together with the ones in the FAIR model, expressed in USD, and international permit price. From the abatement cost curves, it is noticed how mitigation costs are not linearly related to emission reductions, but exponentially related, as the cheapest solutions are the ones implemented first. As the mitigation target is coming close, the most expensive solutions are avoided, and mitigation costs decrease exponentially. The discounted abatement costs are calculated covering the time period between 2005-2050, using the Weitzman method for discounting, which has an initial rate at 4% in 2000, decreasing overtime to 2% in 2050. The discounted cumulated abatement costs are expressed as a fraction of the cumulated, discounted GDP ref (Stehfest et al., 2009).

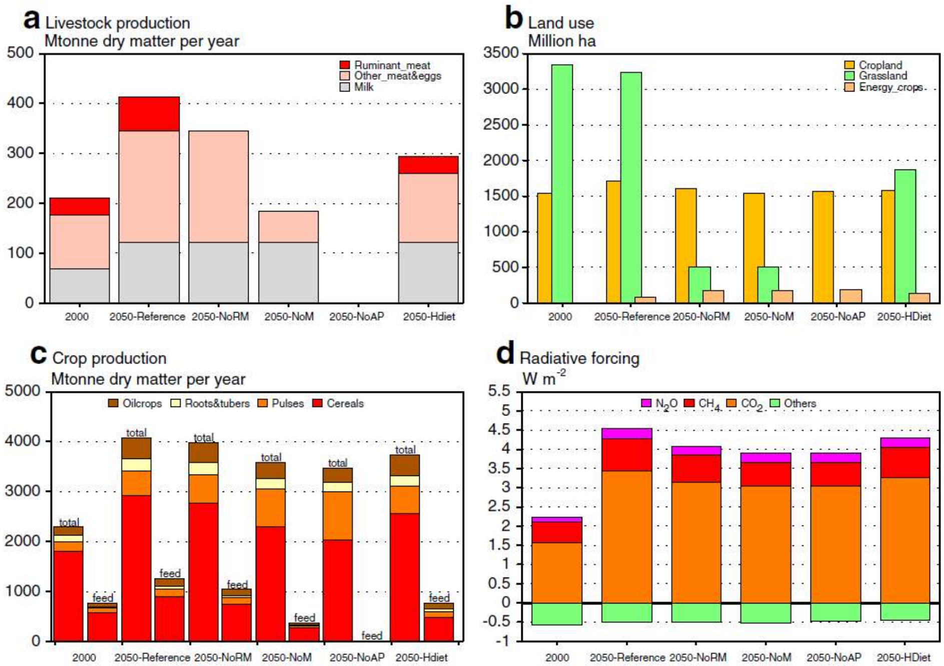
After gathering all the parameters a sensitivity analysis is mandatory, to test how robust the model is. Factors that have been taken into consideration when doing the sensitivity analysis are many. The carbon cycle and carbon uptake from abandoned cropland and pasture is the first factor, and it has been included by analysing different assumptions of CO2 fertilization re-growth of vegetation and abandonment of agricultural land. Regarding fertilization, the increase in net primary production is reduced from 35% to 17,5% by doubling CO2 concentration (Stehfest et al., 2009). Another factor is the recovery of natural vegetation on abandoned agricultural land. To reach maximum net primary production the time of recovery ranges between 2 years and 20 years depending on the type of vegetation and in the sensitivity analysis it was increased by a factor of 2 (Stehfest et al., 2009). Drastic changes in demand are also another uncertainty considered, as it has a huge impact on the agricultural system. A decreasing demand, followed inevitably by a decreasing in land prices, would most likely slow down the improvement of agricultural technology and crop yields. Furthermore, the consequent abandonment of areas of pasture and crop land for feed production would lead to the extensification of the remaining agriculture. In the sensitivity run, intensification is adjust so only half of the abandonment of cropland and intensive pasture would occur at a global scale. The analysis of mitigation costs under the changed CO2 emission and concentration pathways represents the relationship between the distance to the mitigation target and the associated costs. Regardless of these uncertainties, the choice of the discount rate has a determining effect on the results of the climate policy scenarios and mitigation costs, therefore in the analysis it has been used three different discounting methods: UK Treasury, Nordhaus and Stern (Stehfest et al., 2009) plus a constant 5% discount rate used in the IPCC's third and fourth assessment reports.

Reference scenario

A reference scenario has been used in order to reference the assessment of the mitigation policies and the dietary variants. The scenario represents a possible future with assumptions on meat consumption, and no climate policy. The main source used to create it are the OECD Environmental Outlook for the socio-economic projections and the energy sector, the International Energy Agency for energy use and the FAO projections for agricultural production. In the reference scenario, population increase to reach 9 billion people in 2050 alongside a GDP per capita that triples to the average in 2000, and reaches 16 thousand USD (Stehfest et al., 2009) as seen in table 7. This would result in an increase in greenhouse gas emissions to 19.7 CO2-eq, equal to a 78% increase if compared with 2000 levels, with energy-related emissions dominating the overall emissions as it can be seen in table 8.

	Population	GDP	Energy	Industry	Land use
	Million inhabitants	US$ per capita	GtC-eq per year		
2000	6,093	5,584	7.6	0.5	3.0
2030	8,236	10,282	12.9	0.8	3.3
2050	9,122	16,012	15.1	1.0	3.3

Table 8. Global population, GDP per capita and anthropogenic greenhouse gas emissions for the years 2000, 2030, 2050. Source: (Stehfest et al., 2009).



Graph 15. Main characteristics of the reference scenario, plus the four variants with reduced consumption (ruminant meat NoRM, meat NoM, animal products NoAP and supposedly healthy diet HDiet) for livestock production (a), land use (b), crop production (c), radiative forcing (d). Source: (Stehfest et al., 2009).

Population growth and the increase of income per capita, leads to an increase in livestock production (graph 15). However, if there is an increase in crop productivity and livestock production, alongside a gradual shift from ruminant meat to pork and poultry would lead to an expansion of agricultural land of only 11% (graph 15). The total greenhouse gas emissions coming from land-use would increase by 10%, which means from 3 CO_2-eq to 3.3 CO_2-eq between the timeframe from 2000 to 2030 and stay fixed afterwards (table 8). Regarding non-CO_2 GHG emissions for land-use, would increase from 2 GtC-eq in 2000, to 2.8 GtC-eq in 2050 (Stehfest et al., 2009). Between the gases included in the analysis, methane would increase only slightly, as consumption growth would be counterbalanced by an higher efficiency in production and management. Thanks to efficiency, methane emissions are reduced from 0.5 to 0.4 g of CH_4 per kg meat and milk, however, this positive outcome would be not as impactful, as total global methane emissions would increase through enteric fermentation and animal waste from 100 Tg CH_4 per year in 2000 to 170 Tg per year in 2050 (Stehfest et al., 2009). Furthermore, increasing monogastric production at the industrial level, would cause an increase in manure emissions, production of feed crops and fertilizer input.

Focusing on a scenario with dietary change, the strongest impact can be seen in pasture areas, which is reduced by 80% or 2.700 Mha (annual burned areas) with a no ruminant meat or no meat diet, and by 100% or 3.200 Mha for a diet without animal products if compared to the reference scenario (Stehfest et al., 2009). The global cropland area would decrease in all three scenarios, with different percentages. For the NoRM, the reduction would be of 6%, as ruminants requires a higher amount of land for feed crop compared to plant proteins. For the NoM scenario, the increase in cropland area, would enhance further by 4%, while in the NoAP scenario, which includes the substitution of both milk and eggs, would mean the complete abandonment of pasture, but a small increase in the global cropland area for the production of plant proteins. Plant proteins involve the shift from feed crops to food crops, as the land requirements for the different products are largely different it is difficult to assess the direct effect on total land use. Assuming a global mean for production characteristics, the land use requirements results are the ones shown below in table 8. The production of 100 kg of beef protein, corresponding to roughly 500 kg of beef, require 0.6 ha of cropland, while producing the same amount of protein from pulses, would require only 0.25 ha of cropland area, milk would need 0.1 ha, and pork 0.36 ha of cropland (table 9). This numbers would increase if intense production systems would be use for feed rations (in the calculation mentioned the production is discrete, but not intensive, 5.000 kg per hectare for beef, 2.000 kg per hectare for pulses) and consequently decreasing efficiency of feed conversion. The agricultural areas that would not be necessary through dietary changes, could be used as energy crop production or could be revert to natural vegetation to act as a carbon sink. The re-establishment of both temperate, boreal, warm mixed forests, representing 17% of global pasture area, and tropical savannah, scrubland, woodland and forest, representing 35% of global pasture area, would generate more biomass than under grazing land (Stehfest et al., 2009). On the other hand, pastures with low productivity converted in tundra, steppe or semi-desert areas would not be as effective as a carbon sink, as these areas have small carbon stocks.

Table 7 Example of differences in cropland requirement for producing 100 kg of protein from ruminant meat, milk, pork and pulses

Type of product	Protein [kg]	Product (meat/milk) [kg]	Feed conversion [kg feed per kg product]	Crops in feed ration [fraction]	Crop production [kg]	Crop yield [kg ha^{-1}]	Area [ha per 100 kg] protein]
Ruminant meat	100	500	20	0.3	3,000	5,000	0.6
Milk	100	2,500	1	0.2	500	5,000	0.1
Pork	100	500	6	0.6	1,800	5,000	0.36
Pulses	100	NA	NA	NA	500	2,000	0.25

NA not applicable

Table 9. Example showing differences in cropland requirements for producing 100 kg of protein from ruminant meat, milk, pork and pulses. Source: (Stehfest et al., 2009).

In comparison with the reference scenario, all three dietary variants, show considerable reduction (table 10). For the variant without animal products, NoAP, the cumulative emission reductions would be 17% for CO2, 24% for CH4 and 21% for N2O (graph 16).

	GtC eq.
2000	3.0
2050-Reference	3.3
2050-NoRM	1.7
2050-NoM	1.5
2050-NoAP	1.1
2050-HDiet	2.1

Table 10. Land use emissions in 2000 and 2050 for reference scenario and four dietary variants. Source: (Stehfest et al., 2009).

The largest reduction of ghg emissions by product category is related to the substitution of ruminant meat, as shown in graph 16, followed by a large terrestrial net CO2 sink of about 30 GtC over the whole period compared to a net source of 34 GtC in the reference case (figure 16b). Following this step by reducing or eliminating other types of meat or animal products, would not induce a high additional ghg emissions reduction. The contribution given by the carbon sink formed by avoided deforestation contributes 65-75% to the total cumulative emission reduction (Stehfest et al., 2009). Furthermore, dietary variants show a reduction in ghg concentrations of 57 to 76 ppm CO2-eq, plus a reduction of radiative forcing of about 0,5 W m^{-2} compared to reference scenario in 2050 (Stehfest et al., 2009). As it can be seen from the graphs above, even the Healthy Diet option still generates positive results, while still being higher than the more extreme dietary variants. Ghg emissions in this scenario are still 10% lower than the reference scenario, where dietary habits are not contained (Stehfest et al., 2009). Reduced emissions and increased uptake in a HealthyDiet variant result in greenhouse gas concentration being reduced by 30ppm CO2-eq in 2050, compared to the reference case. Mitigation costs when presenting mitigation scenarios on the basis of dietary variants, are lower than the reference scenario. The lower concentration of ghg emissions would lead to less emission reduction in the energy sector, which consequently would lead to a slower increase in the carbon price required to induce changes overtime as it would be easier to reach stabilization changes. Such costs in both the variants NoRM and NoM are reduced by 70% if compared to the reference case, in an another context, such variants represents 0.3% of GDP instead of the 1% of the reference case (Stehfest et al., 2009). It is important to point out, however, how the uptake of CO2 caused by regrowing vegetation would be only a temporary process, decreasing the significant advantage mentioned of the dietary changes overtime. For all variants, while still producing a higher reduction in emissions, the biggest impact is on mitigation costs compared to the reference scenario. For example, the Healthy Diet variant, generates 20% less of emissions, but 50% less in costs when compared to the reference scenario, and that is due to the exponential shape of the abatement cost curves, which make the cost increase or decrease exponentially to the distance to the mitigation target (Stehfest et al., 2009).

Sensitivity analysis

Under the absence of a climate policy, the sensitivity simulations for recovery of natural vegetation, CO2 fertilization and the agricultural system, generates different outcomes both for land-use and CO2 concentration (table 11).

	CO_2-eq. conc. [ppm] in 2050		Discounted cumulated abatement costs as a fraction of discounted cumulated GDP (2005–2050)		Abatement costs relative to the reference case [%]
	Reference	HDiet	Reference 450 ppm	HDiet 450 ppm	HDiet/ Reference 450 ppm
Standard settings	666	636	1.04	0.48	46
Reduced CO_2 fertilization	678	649	1.33	0.63	47
Slower recovery period natural vegetation	671	645	1.18	0.65	55
Reduced agricultural intensification	666[a]	645	1.04[a]	0.63	60

[a]This sensitivity does not affect the reference case

Table 11. Sensitivity analysis results for CO2 fertilization, recovery period of natural vegetation and agricultural system feedbacks, for the scenarios of CO2-eq 2050, abatement costs to meet the 450 ppm stabilization pathway. Source: (Stehfest et al., 2009).

This model shows how dietary changes can deeply impact emission's intensity and therefore being one of the solutions that could be taken into consideration as a mitigation system, alongside with more classic approaches, like changes in the energy system, reforestation and the reduction of non-CO2 gases through add-on abatement technologies. What is interesting about this model, is how it shows that a realistic diet, Healthy Diet, with low meat intake, would have still a significant impact on both climate change and mitigations costs, instead of the more drastic changes that have bigger impacts, but are more unrealistic to reach. There are still some uncertainties regarding the IMAGE model, therefore there are crucial assumptions made with the carbon cycle and the abandonment areas, as in these areas, the regrowth of vegetation leads to a substantial uptake of CO_2. To make the model robust these variations have been tested: variations of CO_2 fertilization, the recovery period of natural vegetation, the potential feedbacks of decreasing demand on intensification in the agricultural system. While changes in CO_2 fertilization would not impact heavily on the results given by the Healthy Diet scenario, the other two reduce the benefits of this diet from 50% to 40% ref. Also discounting methods do not change the reduction in mitigation costs off all variants when compared to the baseline. This model does not take into consideration socio-economic implications that these dietary variants would cause to the general population health and GDP. Agro-economic consequences given by dietary changes are also not considered, that could involve both transition costs and impact land prices.

2.3.7 THE IPAT EQUATION

The I = P x A x T equation, is a formula used to equate the human impact on environment (I) to the product of three factors: population (P), affluence (A) and technology (T). The environmental impact would be represented in the following model as 'GHG emissions'; 'consumption per capita' as affluence and 'GHG emissions per unit of consumption' as technology. The formula is as follow:

$$\underbrace{GHG\ Emissions_c}_{Impact} = Population \cdot \underbrace{\frac{Consumption_c}{Capita}}_{Affluence} \cdot \underbrace{\frac{GHG\ Emissions_c}{Consumption_c}}_{Technology}$$

In this formula, if *$Consumption_c$* is replaced with *$Production_c$* it can be used to evaluate emissions reduction from a production point of view. The following model, will focus on low GHG consumption, which includes the choice of less GHG intensive products by changing patterns or adopting the same product, but with less GHG emissions through product improvement. Below in table 12 there is an overview of all the strategies that could be applied using the IPAT equation. The analysis will focus on the differences and similarities between the evaluated low GHG consumption strategies and the rest. In the low GHG consumption strategy, instead on focusing on the amount of products consumed, it focuses on alternative products which peculiarity is that they are low GHG options.

Climate change mitigation strategy	GHG-IPAT variable
Smaller population	Population
Sufficiency	$\frac{Consumption}{Captia}$
Better instead of more	
New lifestyle	$\frac{Consumption_{category}}{Capita}$
Focus of this study Low GHG consumption (changing patterns)	$\frac{GHG\ Emissions_{item}}{Consumption_{item}}$
Low GHG consumption (product improvement)	$\frac{GHG\ Emissions_{category}}{Consumption_{category}}$
Low GHG user behavior (product use)	$\frac{GHG\ Emissions_{item}}{Consumption_{item}}$
Low GHG production	$\frac{GHG\ Emissions_{item}}{Production_{item}}$

Table 12. Possible mitigation strategies applying the IPAT equation. Source: (Girod et al., 2014).

The first similarity that can be seen is that the behaviour adopted is the same as the low GHG user, who does not change its consumption level. In the low GHG behaviour the attention is on changing the use of the same product, instead of choosing an alternative product. To put it into an example, instead of buying a more efficient car, this behaviour focuses on driving the car more gently. This behaviour would not be included in the analysis below, as it depends mostly on the product itself. To take it back to the car example, lowering energy use by driving gently, depends on the efficiency of the car.

Firstly the model evaluates the climate mitigation potential of choosing climate friendly products. To compared the emissions of the different options, it is needed the life-cycle assessment of the different products, to define the quantified performance of a product system, measured in functional units. The consumption categories considered represent the basic needs of a person, which are: food, shelter, mobility, goods and services. For the goal of this research, the main focus will be on food and more specifically animal products. Different consumption units are used according to the category and product considered, for example, the demand for food is described by its energy content in calories. The options that will be taken into consideration are the widely consumed products, and the alternatives that allow a significant decrease in GHG intensity, called illustrative consumption options. These options refers only to available products as in today, not future innovation, in order to assess their life-cycles. The global targets for 2050 are translated into consumption levels, with the global average consumption per capita in the business as usual scenario (BaU) projected to continually increase similar to past trends, and the food category showing the highest saturation. Furthermore, the RCP2.6 (a ghg emission concentration trajectory adopted by the IPCC, with CO2 emission declining by 2020 and reaching zero by 2100, CH4 emissions reaching half of the 2020 levels and keeping temperature rise below 2 degree Celsius by 2100), are translated into 2.1 ton CO2-eq per capita, based on the population size expected for 2050 (9.1 billion persons) (Girod et al., 2014). After that, per capita emissions are allocated to the different consumption categories, and the intensity results from the division of the allowable emissions by the corresponding global consumption levels, as seen in table 13.

Consumption category		Global consumption (A) [unit/cap]		Global GHG emissions (B) [tCO_2e/cap]		GHG intensity (A/B) [$kgCO_2e$/unit]		
	Unit	2010	2050 BaU	2010	2050 RCP2.6[a]	2010	2050 RCP2.6, global[b]	
Food	Mcal	1048	1131	1.5	0.4	1.4	0.37	0.3–0.6
Shelter	m^2 year	21	29	0.7	0.2	31.9	5.6	5–11
Travel	1000 pkm	6.5	12.6	1.7	0.7	255	53	34–62
Goods	kg	278	410	1.0	0.4	3.6	1.0	0.6–1.0
Services	USD	1830	3613	1.1	0.4	0.6	0.12	0.07–0.14
Total				6.0	2.1			

Note: The emissions in 2010 are in line with the RCPs (Meinshausen et al., 2011), but around 5 Gt CO_2 below the estimates from EC (2011), mainly because they do not include the LULUCF emissions. However, these emissions are projected to decline in all RCP scenarios by 2050 (Vuuren et al., 2011).
[a] Allocation to consumption categories according to the projected distribution in 2050.
[b] Mean value for allocation according to the projected distribution in the year 2050, for the range different allocation and income projections from Girod et al. (2013b).
Source: (Girod et al., 2013b).

Table 13. Global consumption, GHG emissions and GHG intensity for the different consumption categories in 2010 and 2050. Source: (Girod et al., 2014).

To reach such numbers in table 13, alternative allocation methods were considered as well as higher and lower projection of consumption levels. The alternatives include a distribution according to the emission distribution of 2000 and the mitigation costs related to the different categories. This created a range of global GHG intensity targets for comparison with the intensity of the different consumption options. Regarding the food category, the highest intensity is seen in non-vegetal foodstuff, however, also vegetal foodstuff can generate high GHG emissions when transported by air (this type of transport generate 150 times higher CO2 per ton kilometre compared to ocean freight (Girod et al., 2014)) or grown in heated and artificially illuminated greenhouses. Between the different types of meat, also this model shows how ruminant meat has around 10 times higher GHG intensity than both dairy products and non-ruminant meat, like pork and chicken (Girod et al., 2014). Also protein rich vegetables like soy and peas are in line with the GHG intensity target. This issue with non-vegetal options is how the majority of their emissions come from non-fossil GHG, like methane and nitrous oxide. For vegetable foodstuff the emissions usually are generated by energy use in farming, transporting and preparation of food. The low GHG consumption options presented by the model for this category are increasing vegetal foodstuffs; avoiding vegetables transported by air or from heated greenhouses; focus on non-ruminant meat options and avoid meat like beef. Connecting this model with the IMAGE model described before, these dietary changes would help reducing the costs of achieving a 450 ppm CO2-eq goal by about 50% (Girod et al., 2014).

To adopt the low GHG consumption options, there are some obstacles that should be resolved or at least taken into consideration when trying to adopt this model. The obstacles can be separated into four categories and are shown in table 14:

- Consumer preferences (past global trends in consumption)
- Higher total costs (price per functional unit, including all costs for the consumer over the product life cycle)
- Higher complexity (skills necessary to adopt a certain consumption option)
- Higher capital expenditure (only for products allowing lower maintenance and operation expenditure)

Low GHG intensity consumption option	Against consumer preferences[a]	Higher total costs	Product complexity	Higher capital expenditure
Food				
Vegetal food	●		○	
Low GHG meat	○			
Not by air or heated greenhouse	●		○	
Shelter				
Energy eff. building			●	●
Low GHG and renew. energy		●	○	○
Energy eff. appliance			●	●
Travel				
Mode shift	●	○		
E-mobility		●		●
Goods and services				
Re-cycle, re-use			○	
Higher quality (longevity)		○	●	●
Energy extensive/labor intensive		○	●	
Cross-cutting				
Made by RE		●	●	

● Relevant for most products or consumer and ○ relevant for some products or consumers.
Note: For detailed justification of the barrier indicators see Table S2.
[a] Indicated by the past global trend.

Table 14. Indicator of barriers to low GHG intensity strategies regarding preference, costs, complexity or capital expenditure barriers. Source: (Girod et al., 2014).

In the future, meat and animal products are projected to increase, as well as transport by air. Only ruminant meat seem to reach a stabilization (Girod et al., 2014). The complexity is present as low GHG intensity options are difficult to identify and for some categories they also require additional skills. There are different policies that could be applied to eliminate these barriers, one of these, is a correction of market externalities. A tax policy would help decrease preferences and costs barriers as it would change the utility per cost ratio and it would influence also complexity and capital expenditure barriers, however it has not always worked in the past. Another option is default for low GHG consumption, so as to address search complexity, influence preferences and willingness to pay for low GHG consumption with higher costs. Other solutions:

1. Changing the default option: also influence consumer preferences, as a US health study proved with an experiment in a school cafeteria by offering more healthy food choice alongside the usual options. The choice of healthier food increased by 18%, while choice of unhealthy food decreased by 28% (Girod et al., 2014);
2. Labelling for low GHG consumption: to address search complexity, higher capital expenditure and higher total costs. An example is the washing machine market, in which costumers are willing to pay up to 30% more for a washing machine that shows the label A (Girod et al., 2014);

3. Financial incentives for low GHG consumption: financial incentives for pro-environmental consumer behaviour are relevant in size and design. For example, home weatherization can be affect by incentives by a factor of 10 or more depending on program implementation (Girod et al., 2014);

4. Incentive for selling low GHG consumption: The policy could address seller, as they are often more flexible and more capable of nudging consumers towards low GHG consumption.

2.3.8 THE AGLINK-COSIMO MODEL

In the following pages there will be discussed a model, built to understand how alternative market-based mitigation policies would affect livestock production, consumption, trade and most importantly CH4 emissions. The name of the model is AGLINK-COSIMO, which more specifically, is a recursive-dynamic partial equilibrium model of world agriculture (a model that takes into consideration only a part of the market, while keeping the rest unchanged, and analyse it in order to reach the equilibrium) (Key and Tallard, 2009). The model was created by the OECD (Organization for Economic Cooperation and Development) and the FAO to provide forecast that reach 10 years in the future to inform discussions of emerging policies and they are published annually. In this model livestock is defined by supply, demand and the market clearing conditions. The supply of livestock commodity *i* in region *n* equals the number of head (stock) $H_{i,n}$ times the yield per head $Y_{i,n}$:

$$S_{i,n} = H_{i,n}Y_{i,n}$$

The head of livestock is a function of the livestock commodity price $P_{i,n}$ net of the per-unit carbon tax $T_{i,n}$, lagged stock $H^{-t}_{i,n}$ (which number changes according to commodity), and policy variables $Z^{h}_{i,n}$ (e.g. productions quotas):

$$H_i = H\left(P_{i,n} - T_{i,n}, H^{-t}_{i,n}, Z^{h}_{i,n}\right).$$

The yield per head depends on the livestock commodity price net of the tax, an index of feed prices $P^{f}_{i,n}$, and a yield trend $YT_{i,n}$:

$$Y_{i,n} = Y\left(P_{i,n} - T_{i,n}, P^{f}_{i,n}, YT_{i,n}\right).$$

Demand for a livestock product is a function of its own price, the price substitute livestock products $P_{j,n}$, and the region's gross domestic product and population:

$$D_{i,n} = D\left(P_{i,n}, P_{j,n}, GDP_n, POP_n\right).$$

The world price P^{w}_{i} is transmitted to the domestic price according to:

$$P_{i,n} = P\left(P^{w}_{i}, XR_n, Z^{p}_{i,n}\right),$$

XR_n represents the exchange rate, while $Z^{p}_{i,n}$ stands for policy variables (e.g., tariffs). Net trade (export – imports) is defined as the excess supply:

$$NT_{i,n} = S_{i,n} - D_{i,n}.$$

Goods produced in different regions are considered to be homogeneous, and the model is closed by requiring the excess supply all regions to equal zero:

$$\sum_{n=1}^{N} NT_{i,n} = 0.$$

With this approach for the excess supplies, the solution of the model generates country net trade positions but not bilateral trade flows. The model is recursively dynamic (a model that involves two or more periods, in which the consumer or producer trades off benefits and costs across the two times). An example is portrayed in cattle, where the investment in breeding animals is presumed to increase when the expected revenues from future sales exceed the market price at slaughtering. At the same time, the number of animals for reproduction influences the availability of said livestock for slaughtering. This leads to the negative output, in the short run, for prices related to the elasticity of meat. On the contrary, for poultry, the output price is assumed to be calculated only by taking into consideration the feed index cost and supply is the result of the sum of domestic demand and the trade balance. In the model used, livestock production interacts with crop production sectors through feed demand, which is determined by own and cross-feed prices (which elasticities reflects requirements for protein and energy and the degree of substitutability among different feeds) and by the level of livestock production itself. All the parameters used for the OECD countries are supplied by the member states, from national models or expert assessments. Many of these modules are calibrated through a system of annual questionnaires, after those, the baseline predictions are merged to generate a common baseline, which is later reviewed by both OECD and FAO staff and experts and published in the annual Agricultural Outlook. The model used refers to 2008, by using data from 2007 and forecasting market trends up to 2017. Although, outdated as data, it is still relevant to analyse this results to understand how such a model could work in real life. In the analysis a carbon tax is introduced in 2008, and the data of that year are compared with the policy-induced outcomes of 2013 (year specifically chosen as it is far enough to allow the livestock stock to adjust to the relative price changes caused by the tax).

The first calculation is the region and commodity-specific per-unit tax based on embodied CH4 emissions:

$$\begin{aligned} T_{i,n} &= P^C C_{i,n}/Q_{i,n}, \ \text{for } i = \text{chicken, pork, sheep meat;} \\ &= P^C\left(C_{i,n}^{nondairy} + \theta_n C_{i,n}^{dairy}\right)/Q_{i,n}, \ \text{for } i = \text{beef;} \\ &= P^C(1-\theta_n)C_{i,n}^{dairy}/Q_{i,n}, \ \text{for } i = \text{milk;} \end{aligned}$$

- P^C stands for the price of CO2-eq emissions in US dollars per ton;
- $C_{i,n}$ is the total of CH4 emitted during the production, in tons using the CO2-eq;
- $Q_{i,n}$ is the total output, in tons;

While for chicken, pork and sheep meat, all methane emissions are related to meat, for beef, these emissions come from both dairy and non-dairy cattle. For dairy cows, only a share of emissions is attributed to beef, ϴ, while the remaining share is attributed to milk (1 - ϴ). The share ϴ, is based on the estimated revenue shares of beef and milk per cow, which varies by region.

$C_{i,n}$ is calculated differently for Annex 1 countries and for non-Annex 1 countries. The firsts have $C_{i,n}$ calculated according to 2005 UNFCCC national inventory reports, which includes methane emissions from both enteric fermentation and manure management for the major livestock categories. For the latter, $C_{i,n}$ is calculated with the IPCC Tier 1 methodology, which is the following:

$$C_{i,n} = \left(EF_{i,n}^{enteric} + EF_{i,n}^{manure}\right) * H_{i,n}$$

In which both $EF_{i,n}$ are the IPCC Tier 1 emission factors, while $H_{i,n}$ represents the 2005 livestock inventory reported by FAOSTAT.

	Methane emissions (Mt CO_2-eq)		
	2008	2013	Percent change
Annex 1 - Select Countries	685	699	2.0
Non-Annex 1 - Select Cos.	960	1,099	14.6
World	2,174	2,390	9.9
North America	249	254	1.8
Latin America	510	570	11.8
Europe	303	310	2.3
Africa	294	331	12.6
Asia and Pacific	712	817	14.9
Oceania	105	107	1.8

Table 15. Total methane emissions from livestock in the years 2008 and 2013. Modified 2008 AGLINK-COSIMO model estimates using IPCC, UNFCCC, FAOSTAT data. Source: (Key and Tallard, 2009).

The emissions calculated in table 15, start at 2.17 Gt CO2-eq CH4 globally in 2008. A number near to the estimations made from USEPA, which are 2.16 Gt CO2-eq and was calculated in 2005, and the ones made by Steinfeld et al. of 2.2 Gt CO2-eq (Key and Tallard, 2009). Using the AGLINK-COSIMO baseline forecasts, it is assumed that global emissions will increase 9.9%, so to reach around 2.39 Gt CO2-eq between the years 2008 and 2013 (Key and Tallard, 2009). This increase will happen mainly in non-Annex 1 countries (93% of the overall increase) in this order Asia leading all countries with a percentage of 49%, followed by Latin America with 28% and lastly Africa with 17%. While in the Annex 1 countries, such as Europe, North America and Oceania, the increase will reach only 1 to 3 percent.

According to table 16, beef production is responsible for 63.3% of total global livestock CH4 emissions, followed by milk, sheep meat, pork and poultry, of which 31.5% is traced back to the selected Annex 1 countries, while 44.2% is of the selected non-Annex 1 countries present on the table, however, all non-Annex 1 countries are responsible for 68% of methane emissions (Key and Tallard, 2009).

Per-head these emissions are higher in Annex 1 countries compared to the non-Annex 1 countries, and that is caused by the fact that per-head Annex 1 countries produce more meat and milk, which as mentioned in the previous chapter are the productions that cause the highest emissions. However, a greater output per head means average carbon-equivalent emissions per ton of livestock to be lower for meat and milk in those countries. For pork, sheep meat and poultry the results change and Annex 1 countries are responsible for higher emissions.

CH4 emissions alter significantly between different areas of the world, due to different technologies production practices, such as animal genetics, feed quality and manure management. However, these differences are relatively minor if compared to differences between species: while a ton of beef generates 13.3 t of carbon-equivalent methane emissions in North America and 24.5 t in South America, when considering poultry the average of carbon-equivalent emissions drops respectively to 1.9 and 0.6 t (Key and Tallard, 2009).

From table 16, it is possible to see the tax as a share of the output price for livestock commodities with CH4 emissions valued at 30 USD/t CO2-eq. Given that beef has the highest rate of emissions per ton, it faces also the highest average tax rate, exactly 23.8% and because of the intensity of production it affects more Annex 1 countries (Key and Tallard, 2009).

	Carbon tax as a share of price (%)				
	Beef	Pork	Poultry	Sheep meat	Milk
Annex 1 - Select Countries	15.8	2.1	3.2	15.8	3.2
Non-Annex 1 - Select Countries	26.6	1.7	2.5	12.4	6.1
World	23.8	1.8	2.7	16.8	4.8
North America	10.5	3.5	3.5	11.6	4.0
Latin America	29.6	1.5	1.2	25.2	7.8
Europe	18.4	1.4	3.2	13.7	2.9
Africa	39.2	1.3	2.0	25.9	9.0
Asia and Pacific	26.2	1.6	2.9	11.8	5.1
Oceania	26.0	4.4	1.1	19.9	4.2

Table 16. Carbon tax as a share of the price for the year 2008. AGLINK-COSIMO model estimates with IPCC, UNFCCC and FAOSTAT data. The carbon tax is based on the carbon price 30 USD/t CO2-eq. Source: (Key and Tallard, 2009).

How does the tax work? The tax creates a wedge between the market price and the price producer receive, which leads to a contraction of the supply as producers demand a higher market price to produce the same amount of output. The equilibrium that is reached after the tax has been implemented is characterized by a higher price for all commodities and it proportionally increases more for carbon-intensive goods. With such consequences, both consumption and production of the more carbon-intensive goods should decline, but it could be counter-productive as it could lead to an increase in the demand for less carbon-intensive goods, which would not solve the issue. The effect of such tax projected to 2013 would show a decline in beef and sheep meat production, respectively by 5.7% and 3.6% (Key and Tallard, 2009). The production of the before mentioned livestock, like poultry, pork and milk would increase to substitute the higher-taxed types of meat. Furthermore, the tax would affect differently the countries' productions, for example, when considering Annex 1 countries, EU, USA and Japan would face a smaller decline in beef production than Canada, Russia and Turkey, reflecting the relative tax rates in the markets where the beef is traded.

While at country-level the percentage change in production reflects the percentage decrease in methane emissions, the emissions rates differ between countries, meaning that each country contributes with a different share to the total production and the total emissions within a specific region. Thus, for regions, the percentage change total production may differ from the percentage change in methane emissions. According to the results of table 17, the tax would generate a decline in global annual CH4 emissions of 4.6% in 2013, from the baseline level mentioned above of 2.39 Gt CO2-eq (Key and Tallard, 2009). The decline is more evident for the selected non-Annex 1 countries, a decrease of 4.5%, reflecting the larger decline in beef production.

	Change in methane emissions (%)					
	Beef	Pork	Poultry	Sheep meat	Milk	Total
Annex 1 - Select Countries	−5.7	1.1	0.7	−3.7	−0.6	−3.9
Non-Annex 1 - Select Cos.	−6.3	−0.2	−0.3	−3.5	0.2	−4.5
World	−6.8	0.4	0.2	−4.4	0.9	−4.6
North America	−4.5	2.0	1.2	−2.5	−0.9	−3.1
Latin America	−7.0	1.8	1.3	−5.6	−1.9	−6.3
Europe	−5.5	0.4	−0.1	−3.1	0.5	−3.3
Africa	−10.7	−0.1	−0.9	−5.7	0.5	−6.8
Asia and Pacific	−6.4	−0.3	−0.4	−3.2	3.0	−3.2
Oceania	−7.9	−0.5	1.1	−4.4	−5.6	−6.5

Table 17. Policy-induced change in CH4 emissions in 2008. AGLINK-COSIMO model estimates with IPCC, UNFCCC and FAOSTAT data. The carbon tax is based on the carbon price 30 USD/t CO2-eq. Source: (Key and Tallard, 2009).

The tax would inevitably generate revenues for the countries, with an estimate of USD 68.4 billion global tax revenues, of which about USD 48 billion collected by non-Annex 1 countries. If the price would be set at USD 15/t CO2-eq, emissions would decrease about 2.8% from baseline 2013 levels. As the price increases the emissions decrease, however, because global methane emissions are estimated to increase 9.9% between the timeframe 2008-2013, the carbon price should be of USD 100/t CO2-eq to maintain the emissions at the same level as 2008 (Key and Tallard, 2009). The price elasticity of methane emissions is estimated to be 0.02 at the price of USD 20/t CO2-eq in this model (Key and Tallard, 2009). Such price elasticity results quite small in the model used here, because producers are not allowed to adjust their production technology in response to the methane tax.

Such a tax is plausible to be applied in the near future only for Annex 1 countries, as developed countries possess the infrastructure for monitoring and also reporting methane emissions at the national level. Furthermore, most developed countries have committed to reduce emissions under international agreements. This action taken only on Annex 1 countries, would still impact non-Annex 1 countries greatly, as imports from into Annex 1 would increase while exports would decrease and this would lead to an increase in production in non-Annex 1 countries of 1.5% (Key and Tallard, 2009). Consequently the decrease of CH4 emissions in the Annex 1 countries would be offset by the increase in production in non-Annex 1 countries, bringing the total overall reduction of CH4 emissions to only 0.5% (Key and Tallard, 2009).

Sectoral emissions trading under the ANGLICK-COSIMO Model

In the following segment it will be discussed the permit revenues flows under a sectoral emissions trading scheme, also known as the cap and trade scheme. The caps are set on emission levels for the timeframe 2008-2013, depending on the policy scenario considered and they are constant in the 5-year period. At the beginning of the period (2008), a set of allowances equivalent to the emissions cap is allocated with no costs involved to the participating national governments. If a country goes over the cap by increasing their CH4 emissions above it, it needs to purchase emission permits, while if a country stays below such cap, it can sell the permits it did not use. In the following analysis the emission permit price will remain constant at USD 30/t CO2-eq and countries are assumed to have the ability to sell and purchase an unlimited amount of permits through a emissions permit market. To make the model used and the analysis tractable, it is assumed that each country, which is participating, adopts the same mitigation strategy, which is, a tax on production based on embodied CH4 emissions. This model is not shown for its likelihood to happen (it is very unlikely that all countries would participate in an international carbon tax scheme), but it shows important features of sectoral emissions trading. The tax rate chosen influences the levels of production, consumption, trade and emissions. Furthermore, the tax price is set at USD 30/t CO2-eq. To see the impact of the scheme, three scenarios are explored in table 17 below, the first of which as the cap set at 100% for all countries on 2008 emissions, starting by net emissions permit revenues from 2013. The model shows how countries from Africa, Asia and Latin America purchase permits in 2013 as their total production is estimated to increase when compared to 2008 levels of production, even when the tax is applied, while countries from Europe, North America and Oceania sell permits as their production decreases. The livestock sector is estimated to purchase permits worth around USD 3.2 billion from outside of the sector, assuming perfect elasticity of emissions' demand (Key and Tallard, 2009). The second scenario sets the cap to 104.5% for 2008 emissions (Key and Tallard, 2009), in this case, while Asia remains a net purchaser of permits, the other regions become all net sellers. In this scenario, by 2013, there are no movements of permits between the livestock sectors and other sectors. As there would be a balance in the livestock sector, the tax would not influence the market of other sectors and therefore would not influence the global price of carbon permits. The third scenario captures the changes in the livestock sector by setting the cap at 84.5% of 2013 emissions for Annex 1 countries, and 100% of 2013 emissions for non-Annex 1 countries (Key and Tallard, 2009). In this scenario there still is balance in the livestock sector, however developed regions (including North America, Europe and Oceania) are estimated to purchase approximately USD 2.4 billion from the developing regions of Latin America, Asia and Africa (Key and Tallard, 2009). In these scenarios, as the carbon rate remains unchanged, producer and consumer responses as well as methane emissions do not vary, so changing the cap caused a change in the distribution of net permits revenues while keeping the global environmental benefits stable.

Carbon permit sales (+) and purchases (−) (million USD)	Scenario 1: 100% of 2008 emissions, all countries	Scenario 2: 104.9% of 2008 emissions, all countries	Scenario 3: 84.5% of 2013 for Annex 1 100% of 2013 for non-Annex 1
Annex 1 - Select Countries	391	1,397	−2,445
Australia	114	222	−214
Canada	267	318	23
EU-27	233	548	−893
Japan	−5	17	−68
New Zealand	41	87	−74
Russian Federation	−100	−8	−144
Turkey	16	45	−39
Ukraine	−4	23	−64
USA	−169	146	−972
Non-Annex 1 - Select Cos.	−2,691	−1,282	1,500
Argentina	75	170	158
Brazil	−817	−399	516
China	−968	−646	509
Egypt	−27	−18	−13
India	−758	−420	110
Indonesia	26	54	66
Korea	−3	2	−1
Mexico	72	126	36
Nigeria	−16	9	50
Pakistan	−280	−184	56
South Africa	6	25	11
World	−3,191	0	0
North America	98	464	−948
Latin America	−722	27	1,083
Europe	99	544	−1,138
Africa	−431	1	678
Asia and Pacific	−2,389	−1,344	614
Oceania	154	309	−288

Table 18. Carbon permit sales and purchases for 2013. AGLINK-COSIMO model estimates with IPCC, UNFCCC and FAOSTAT data. The carbon tax is based on the carbon price 30 USD/t CO2-eq. Source: (Key and Tallard, 2009).

The government revenues, with this scheme (sectoral emissions trading), would derive from both domestic tax on CH4 emissions and from net emission permit sales, which could be negative, as shown in table 18. If the sectoral policy described in the third scenario would be applied, government revenues would increase by 2013 of approximately USD 33.0 billion in non-Annex 1 countries and USD 17.7 billion in Annex 1 countries. Such revenues should be used to compensate the loss of profits that affected producers and the loss of welfare experienced by consumers caused by the policy. Nonetheless the revenues may not cover the entire damage for producers and consumers, even in the non-Annex 1 countries, which earned revenues from permits sales. How to understand how big these revenues should be to cover all the costs and loss of revenues perceived by producers and customers? The change in producer revenues and consumer costs need to be estimated as shown in table 19 below. In the table (second column) it can be seen how much consumer expenditure would be affected if consumption remained the same as the pre-tax phase. The change in costs are represented by the amount they would have to pay to purchase the same basket of commodities that they would have purchased without the tax. The higher commodity prices caused by the tax would be reflected by the increase in consumer expenditures on livestock products. While the second column shows the compensation that consumer would need to keep unchanged their consumption, it is not excluded that they could adjust at these policy-induced changes by fixing their mix of goods they purchase. Is this would be true, like changing their purchase from beef to poultry, would require less compensation than the one indicated to keep the same level of welfare as the before-tax period. In the third column it shows the changes in the producer revenues. In most countries producer revenues would decline because of lower producer prices, however in some countries, such as Japan, revenues would increase due to the increase in demand for relatively low-carbon intensive products. This would happen because of the differences in commodity and region that affect the impact of the tax on production. The change in producer revenues in overestimated as it does not take into consideration how producers spend a considerable amount of their revenues on production costs, which means that a part of the change would affect provider of feed and other inputs. In the table it can be seen how Annex 1 countries costs would weight over consumers, while in non-Annex 1 countries producer would have to bear the majority of the costs. As it can be deducted by this model, the main driver of these results is beef.

	Change (million USD)		
	Government revenue	Consumer costs	Producer revenue
Annex 1 - Select Countries	17,720	23,427	−15,570
Australia	1,886	350	−2,721
Canada	810	757	−3,593
EU-27	5,304	7,219	−4,129
Japan	381	3,125	1,842
New Zealand	828	66	−3,281
Russian Federation	1,841	1,824	−1,954
Turkey	538	371	188
Ukraine	507	461	−373
USA	5,625	9,255	−1,550
Non-Annex 1 - Select Cos.	32,981	14,320	−25,552
Argentina	2,022	791	−1,767
Brazil	9,874	3,396	−9,134
China	8,048	4,125	−15,013
Egypt	211	512	1,027
India	7,768	2,352	594
Indonesia	608	475	−1,289
Korea	114	256	205
Mexico	1,069	518	363
Nigeria	587	315	−778
Pakistan	2,283	991	506
South Africa	396	588	−265
World	68,401	52,613	−44,318
North America	6,435	10,012	−5,142
Latin America	17,108	7,533	−14,707
Europe	7,853	10,029	−6,249
Africa	9,936	6,675	−8,125
Asia and Pacific	24,354	17,949	−4,094
Oceania	2,714	415	−6,001

Table 19. Sectoral emissions trading, scenario 3. AGLINK-COSIMO model estimates with IPCC, UNFCCC and FAOSTAT data. The carbon tax is based on the carbon price 30 USD/t CO2-eq. Government revenue = carbon tax revenue + net permit sales. Consumer costs are expenditures on the pre-tax 2013 level of consumption. Scenario 3 sets an emission cap equal to 84.5% of 2013 emissions for or Annex 1 countries and 100% of 2013 for non-Annex 1 countries. Source: (Key and Tallard, 2009).

Limitations of the model AGLINK-COSIMO:

This model does not include possible technological responses as the emission reductions result only from changes in output. Furthermore, for the way the tax is presented it does not give incentives to adopt mitigation technologies from the producer side, as the tax is based on national emissions and not individual ones. This issue, however, could be solved by the incentives given to governments to promote mitigation technologies and practises as to increase permits revenues. Such a solution, would lead to a greater reduction in emissions and to a smaller contraction in production than the one anticipated in the model. The 5-year span in which the model is calculated does not give enough time to actually consider the implementation of mitigating technologies, so that is why they will not be considered. Another limitation of the model is how it takes into consideration only CH4 emissions, while excluding other essential ghgs, such as N2O from manure management and CO2 emitted by land use change. This was a conscious decision, as methane is the only gas between the ones mentioned that is easy to attribute to the livestock, making it likable that the future mitigation policies will focus on CH4. The possible inclusion of other sources of GHGs emissions in the carbon tax, would not only increase the tax itself, but also alter the relative taxes across regions and commodities. As an example, Brazil, would face a substantially higher tax and suffer from bigger changes in production effects with the inclusion of other GHGs emissions, given the high deforestation and land-clearing, both high on emissions, that happens regularly in such country. The last limitation that needs to be taken into consideration, before analysing and applying this model is that the only emissions considered are the ones coming from meat and milk, excluding other animals outputs and functions, such as leather, wool, savings and insurance. These other sources can have a big impact in the final output, especially when considering cattle, for which these animals functions represent the majority of the economic value of the animal in developing countries. If these outputs were included in the carbon tax, this would be lower for meat and milk in regions where the before mentioned functions are important, like South Asia and sub-Saharan Africa.

2.3.9 OTHER TECHNIQUES

- Sequestering Carbon mitigation Carbon Dioxide Emissions. Carbon sequestration happens differently depending on the activity it is generated by. For livestock, sequestration could happen through improvement of pastures; in land-use change, the focus should be in slowing and eventually stopping completely and reversing deforestation. According to Vlek et al. (Steinfeld and Wassenaar, 2007), the only way to do so would be through the intensification of agricultural production on some lands by increasing fertilizer inputs. While fertilizer would also generate carbon emissions, they would still be outweighed by the avoided emissions that would come from deforestation. However, this intensification policy should be highly regulated otherwise it would cause socio-political problems. The potential of C sequestration from cultivated or degraded soil is very high, as their sink capacity reaches 50% to 66% of the C loss from soils of 42 to 78 gigatonnes of C (Steinfeld and Wassenaar, 2007). IPCC analysis show how improved practices typically allow soil C to increase of about 0.3 tonnes of C per hectare per year rate (Steinfeld and Wassenaar, 2007). Another way to generate net sequestration is through improved grassland management, by use of trees, improved pasture species (highest potential as a carbon sink as it is the largest anthropogenic land use), fertilization alongside other measures. The sequestration would differ according to the type of land, for example dry land, while usually found in areas with low carbon intensity it also keeps trapped C for a longer time then wet soils, therefore being cost-effective and improving soil and restoration.

- Mitigating Methane Emissions through Improved Manure Management and Biogas. Methane emissions coming from manure, can be already been taken down with existing technologies. The first option comes from a balanced feeding, followed by anaerobic digestion, flaring and burning or special biofilters. Biogas alone can achieve a 50% reduction in an area with a cool climate, and it could go even higher in warmer climates (Steinfeld and Wassenaar, 2007). The techniques that could be used to store biogas in liquid form are already present in the form of tanks, pits, covered lagoons or other liquid storage structures.
- Mitigating Nitrogen Loss. The mitigation pathway for nitrogen loss is to increasing low animal N assimilation through more balanced feeding, obtained by optimizing proteins and amido acids to match exactly the requirements. Other feeding practices include grouping animals by gender and phase of production so as to tailor feed according to physiological requirements. Regardless of more efficient feeding mechanisms, the nitrogen coming from manure is still very high, but it can be nearly completely eliminated with storage, that can be used, alongside CH_4 storage, to produce biogas. Another option are nitrification inhibitors (NIs) that can be added to urea or ammonium compound, to retard or prevent conversion of ammonium-nitrogen to nitrate-nitrogen. The costs encountered to adopt NIs would be offset by the increase N uptake efficiency of crop and pasture, however as it is another chemical it could be perceived negatively by the public.

Conclusion

Livestock, alongside its products and its management as shown in the analysis of this thesis is clearly damaging the environment with its intensive methods of production and its increasing demand in developing countries. However, not only it contributes to climate change, but it also damages animal welfare, as domesticated animals are social animals and their developed group dynamics are disrupted or worse, eliminated by modern farming methods that force animals to live in overcrowded spaces or in complete isolation. This leads to the danger of density-promoted diseases generated by the stress felt by the animal itself. What is also at risk is human health, as the high intake of animal products, and in particular meat products (happening mostly in western countries and increasing rapidly in developing countries as shown in chapter 1) has been shown to be related to obesity and an elevated incidence of several chronic diseases, such as type 2 diabetes, hyperglycemia, hypertension and coronary heart disease (CHD) and some type of cancer too (Smil, 2002). However, regardless of the damage it generates, meat will always be difficult to eliminate or at least diminish unless a drastic change does not happen, not only at a government level, but also at a personal level. Changing people's minds about what they should and should not eat it not easy, as more often than not, dietary habits are engrained in our culture and they are seen as something extremely personal. So having someone demanding to stop eating your favourite burger from your favourite fast food would mostly likely generate offence and anger. However, action does not only happens in people's home, regardless of its importance. In my opinion there is a step by step guide to follow in order to reach optimal results and reduce animal products consumption to a minimum, or even reach the non-animal products scenario (even though reaching such a goal is utopistic). Firstly, government should enact an educational program, starting from schools, followed by advertisements on television and giving incentives to the food industry (i.e. companies that create partnerships with cafeterias in schools and firms) to include more non-animal options. The educational program, should focus on environmental issues, climate change as well as dietary habits consequences, so as to develop a "new normality" with a diet that includes mostly seasonal and local vegetal foodstuffs and limits animal products, especially the ones coming from intensive farming. Secondly, when the population is more informed about these issues, governments should consider forming new policies to reduce greenhouse gas emissions coming from livestock. In my opinion, while all the models and techniques above have a lot of limitations that makes them either too futuristic (by including technologies or suggesting approaches not yet available as in right now), too specific (by excluding crucial activities related to livestock that should be considered when calculating GHG emissions, or by omitting types of GHG that are highly related to livestock and have the same damaging impact, if not more than the gases considered) or too theoretical, without providing actual mitigation options. A semi-realistic option that could be adopted is a new version of the AGLINK-COSIMO model, let's say a AGLINK-COSIMO model 2.0, which works similarly to the model explained in the previous chapter, but more complete to properly affect livestock production, consumption and trade. The first change that I would apply to the AGLINK-COSIMO model is to include not only methane emissions, but also nitrogen and carbon dioxide, so as to cover the main three gases produced by livestock. This would require further research on all the activities related to livestock and how much ghg they generate. Furthermore, as mentioned before, if all these gases would be considered it would create an imbalance between countries as in some deforestation and other polluting and damaging activities are more present than in other countries, forcing them to pay a way higher tax. However, this could be counterbalanced with some incentives to these countries to stop these activities and help re-forestation as well as a shift into more sustainable production practices. Incentives would be also necessary for producers, as the tax would be applied at a national level and not at an industrial level, and they would in the form of incentive to increase permits revenues and promote mitigation technologies. Lastly, the 5-year span used in the model to consider technological implementation should take into consideration at least double the years, to allow to see the effect and work of the mitigation technologies.

This can work only if there is a tight and organized collaboration between countries, which decided to put the climate change issue in their agenda and want to take action. Without this collaboration, the plan would not work as the inevitable disparity between countries would only worsen in this scenario, unless there is a system of incentives to help countries more in need and being stricter with countries that have the capacity to address the matter. Alongside this collaboration, the urgency to take action should also be implemented in the population and create this need and want to do something before it gets too late. The current trend of veganism, activism and protests between a younger audience that has been increasing in the last few years certainly does help, but it is not enough.

I would like to conclude with an honourable mention to the act the “Green New Deal”, an ecological and social act to transform society by tackling both climate change and inequality (issue not directly discussed in our analysis, but still very highly related to climate change). Its goal is to decarbonize and restructure societies with a project to move away from fossil fuel based economies as well as paying attention to social justice. The results would be the creation of millions of jobs, to replace those lost in the fossil fuel industry, racial and economic equality, increase community resilience to climate change, ecosystem restoration and reduced pollution and reaching zero greenhouse gas emissions by 2050. While being very optimistic, this plan is not unreachable if applied by every country with a pro-positive attitude and it would be the first step to take to properly address the climate change issue which is becoming more urgent by the minute. The options to diminish GHG emissions, especially those coming from livestock, are plenty and some already exist and are relatively easy to apply, there is only the necessity to understand why it is mandatory to do something and take action.

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