# Animal Agriculture is the Leading Cause of Climate Change

**A Climate Healers Position Paper**
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"*A (position) white paper is an authoritative report or guide that informs readers concisely about a complex issue and presents the issuing body's philosophy on the matter. It is meant to help readers understand an issue, solve a problem, or make a decision*" – Wikipedia.

## Abstract

In this paper, we present the results of a Global Sensitivity Analysis (GSA) proving that animal agriculture is the leading cause of climate change, responsible for at least 87% of greenhouse gas emissions annually. The burning of fossil fuels is currently the leading source of human-made carbon dioxide (CO2) emissions. However, climate change is caused by cumulative human-made greenhouse gas and aerosol emissions and not just current CO2 emissions alone. While humans have been burning fossil fuels for a little over 200 years, we have been burning down forests for animal agriculture for well over 8,000 years. For the GSA analysis, we use factual data from the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) and other peer-reviewed scientific sources. We show that we need to transition to a global plant-based economy first and that blindly eliminating fossil fuel usage first will accelerate the warming of the planet. We show that the annual methane emissions from animal agriculture alone cause more incremental global warming than the annual CO2 emissions from all fossil fuel sources combined. We further show that the transition to a global plant-based economy has the potential to sequester over 2000 Giga tons (Gt) of CO2 in regenerating soils and vegetation, returning atmospheric greenhouse gas levels to the "safe zone" of under 350 parts per million (ppm) of CO2 equivalent, while restoring the biodiversity of the planet and healing its climate. This paper clearly illustrates why the scientific community, government institutions, corporations and news media, who vastly underestimate the role of animal agriculture and focus primarily on reducing fossil fuel use, need to urgently change their priorities in order to be effective.

## 1. Introduction

The burning of fossil fuels is undoubtedly the leading source of human-made Carbon diOxide (CO2) emissions today. CO2 is the most powerful human-made greenhouse gas in terms of its radiative forcing, which is the average energy trapped by the greenhouse gas per unit time per unit area of the Earth's surface, typically measured relative to the base year 1750. In the absence of active reforestation efforts, CO2 is a long-lived greenhouse gas as it persists in the atmosphere for tens of thousands of years. The Fifth Assessment Report (AR5)[1] of the Intergovernmental Panel on Climate Change (IPCC) estimates the mean radiative forcing of human-made CO2 to be 1.68 Watts/square meter ($W/m^2$). The next most powerful human-made greenhouse gas, methane, with a mean radiative forcing of 0.97 $W/m^2$, lingers in the atmosphere for an average of 8-10 years before it reacts with oxygen free radicals and also converts into

$CO_2$. As such, it is tempting to conclude that a single-minded focus on the reduction of fossil fuel burning to minimize future human-made $CO_2$ emissions is the best strategy to address climate change. Indeed, the global scientific community, government institutions, corporations and news media have adopted this strategy without much questioning. They have also unquestioningly accepted the United Nations (UN) Food and Agricultural Organization (FAO)'s estimate)[2] that the lifecycle emissions of the animal agriculture industry sector is a mere 14.5% of global human-made greenhouse gas emissions, which justifies their urgency of reducing fossil fuel burning over dealing with the animal agriculture sector.

In this paper, we will show that this strategy of focusing exclusively on the reduction of fossil fuel burning will accelerate climate change, potentially to the point of no return. Using a Global Sensitivity Analysis (GSA) method, we will show that the UN FAO's 14.5% estimate for the lifecycle emissions of animal agriculture is incorrect and that the correct estimate is at least 51% as calculated by Goodland and Anhang[3] and their lower bound can be tightened to at least 87% of global greenhouse gas emissions. Therefore, animal agriculture is the leading cause of climate change.

Furthermore, we will show that a global transition to a plant-based economy has the potential to sequester over 2000 Giga tons (Gt) of $CO_2$ in regenerating soils and vegetation, returning atmospheric greenhouse gas levels to the "safe zone" of under 350 parts per million (ppm) of $CO_2$ equivalent ($CO_2e$), while restoring the biodiversity of the planet and healing its climate.

The organization of this paper is as follows:

In Section 2, we will examine how waste "exhaust" from human activities changes the Earth's climate. The exhaust can be classified as either greenhouse gases, which heat up the Earth's atmosphere or aerosols, which are atmospheric particles that generally cool the Earth's atmosphere. The main human-made greenhouse gases are $CO_2$ and methane, which are both carbon-based gases and the main human-made aerosols are sulphates, which are primarily produced when we burn coal and oil.

In Section 3, we will examine how the carbon cycle of the planet has been impacted by two main human activities over the past 8,000 years: land clearing or land use change, primarily for agriculture, and fossil fuel burning.

In Section 4, we will examine current agricultural land use and biomass flows to establish that animal agriculture is the primary sector necessitating land clearing, causing climate change. Next, we will compare Local Sensitivity Analysis (LSA) vs. Global Sensitivity Analysis (GSA) on the two main human activities causing climate change: animal agriculture and fossil fuel burning. While LSA is useful for determining the impact of local variations in the current emissions scenario, it can lead to inaccurate results when extrapolated out on a global scale. In contrast, GSA is based on analyzing a global change directly and will lead to more accurate results for that change. Using the GSA method, we will reveal the inaccuracies in the UN FAO's 14.5% estimate on the greenhouse gas emissions contribution of the animal agriculture sector. Next, we will show that the Goodland-Anhang estimate of 51% is truly just a lower bound on the greenhouse gas emissions contribution of the animal agriculture sector. We will then tighten this lower bound using the Carbon Opportunity Cost (COC) estimates of Searchinger et. al. and show that the correct estimate for the annual greenhouse gas emissions contribution of animal agriculture is at least 87%[4].

In Section 5, we will estimate the CO2 sequestration potential and the resultant climate mitigation that can occur with the global transition to a plant-based economy.

Finally, we have included an Appendix detailing the four major miscalculations in the IPCC reports, which systematically undercount the climate change impact of animal agriculture.

In what follows, for the sake of simplicity, we have used the specified statistical mean or the midpoint of uncertainty ranges in the data found in the IPCC reports and other peer-reviewed sources. Our conclusions do not change if we include the underlying uncertainty ranges and other nuances, but we will likely lose clarity in our presentation.

## 2. How Humans Change Climate

Almost everything humans do changes the Earth's climate. The waste "exhaust" from human activities can either heat up the Earth or cool it. Therefore, the question is not whether humans change the Earth's climate, but how much and in what direction. When billions of humans drive cars, burn coal and natural gas for electricity and consume animal products, the exhaust gases and particles from these activities heat or cool the Earth. Exhaust gases such as CO2, methane and nitrous oxide (N2O) heat the Earth. Exhaust particles such as sulphates and nitrates cool the Earth.

The UN IPCC has quantified the impact of each of these exhaust gases and particles in terms of radiative forcing measured relative to their levels that existed in the year 1750 as the base year (see FIg. 2.1)[1]. CO2 is the main human-made exhaust gas that heats the Earth and it is estimated to provide an additional 1.68 $W/m^2$ of heating power relative to its atmospheric concentration in 1750. In other words, the impact of the additional CO2 in the atmosphere since 1750 is like adding a 1.68 Watt continuous heater on every square meter of the Earth's surface.

The next most significant human-made exhaust gas is methane, which has the chemical formula CH4. Methane is estimated to have a mean radiative forcing of 0.97 $W/m^2$ and it lingers in the atmosphere for an average half-life of 8.4 years before it reacts with oxygen free radicals and also converts into CO2. The number one cause of methane emissions is animal agriculture, which contributes 37% of it[2]. Even though the radiative forcing of methane (0.97 W/$m^2$) is less than that of CO2 (1.68 W/$m^2$), the annual emissions of methane has a more significant impact on net radiative forcing, and therefore climate change, than the annual emissions of CO2.

The annual emissions of methane from 2011-2016 was 0.363 Gt, on average[6].

The amount of methane that has accumulated in the atmosphere since 1750 until 2011 is 1.1ppm, which corresponds to 3.12 Gt of methane[27].

Therefore, to a first order approximation, our annual emissions of methane is contributing 0.97x0.363/3.12 = **0.11 W/$m^2$ of radiative forcing**.

In contrast, the annual emissions of CO2 from 2011 to 2016 was 39 Gt, on average[6].

The amount of CO2 that has accumulated in the atmosphere since 1750 until 2011 is 110ppm, which corresponds to 859 Gt of CO2[27].

Therefore, to a first order approximation, our annual emissions of CO2 is contributing 1.68x39/859 = **0.076 W/$m^2$ of radiative forcing**.

Furthermore, since just 45% of the annual CO2 emissions remains airborne due to uptake from land and the ocean, the additional radiative forcing from our annual CO2 emissions that is truly contributing to atmospheric heating is 0.45x0.076 = **0.034 W/$m^2$**, about one-third the methane contribution (please see Appendix for more detailed discussions).

It is important to point out that the IPCC has consistently undercounted the impact of our annual methane emissions by averaging its impact over a 100 year period, even as it warns humanity that catastrophic climate change is imminent within the next 11 years, not 100 years[7]. By doing so, the IPCC is obscuring the safest engineering process for powering down the two major engines of planetary destruction – the Killing Machine (KM) represented by animal agriculture and the Burning Machine (BM) represented by fossil fuel burning. If we don't power down these two machines correctly, we will likely cause various climate tipping points to be breached unnecessarily as we raise global temperatures during the power down process itself.

In the latest report issued in August 2019[6], the IPCC is still using a Global Warming Potential (GWP) of 28 for converting methane emissions to a CO2 equivalent (CO2e). Global Warming Potential (GWP) converts the radiative forcing impact over a specified time horizon of a unit mass of gas, related to the reference gas, CO2. For methane, the GWP over a 100 year time horizon, excluding cloud effects, is 28. When we include cloud effects, it is 34. The GWP of methane over a 10 year time horizon, including cloud effects, is 130[10].

If we used GWP of 130 for methane, then the annual emissions of methane would be 0.363 x 130 = 46.9 Gt CO2e, which exceeds the annual emissions of CO2 (39 Gt CO2).

Since just 45% of the annual CO2 emissions remains airborne[29] each year, the comparison of methane (46.9 Gt CO2e) should be with respect to 0.45 x 39 = 17.6 Gt CO2.

Therefore, the climate change impact of our annual CO2 emissions (17.6 Gt CO2) is about one-third the impact of our annual methane emissions (46.9 Gt CO2e), just as we calculated above.

Indeed, the impact of methane from animal agriculture alone is **37% of 46.9 Gt CO2e**, which works out to **17.3 Gt CO2e**.

This exceeds the impact of all fossil fuel based CO2 emissions, which is **87% of 17.6 Gt Co2**, which works out to **15.3 Gt CO2**.

For reference, please see Table on Page 9 of the latest IPCC report[6].

The third most significant human-made exhaust particles are sulphate aerosols, created mainly during the burning of coal and oil. According to NASA,

> “the sulfate aerosols absorb no sunlight but they reflect it, thereby reducing the amount of sunlight reaching the Earth's surface. Sulfate aerosols are believed to survive in the atmosphere for about 3-5 days.
>
> The sulfate aerosols also enter clouds where they cause the number of cloud droplets to increase but make the droplet sizes smaller. The net effect is to make the clouds reflect more sunlight than they would without the presence of the sulfate aerosols. Pollution from the stacks of ships at sea has been seen to modify the low-lying clouds above them. These changes in the cloud droplets, due to the sulfate aerosols from the ships, have been seen in pictures from weather satellites as a track through a layer of clouds. In addition to making the clouds more reflective, it is also believed that the additional aerosols cause polluted clouds to last longer and reflect more sunlight than non-polluted clouds.”

The radiative cooling effect of human-made sulphate aerosols together with their cloud adjustments is calculated to be -0.95 W/m$^2$ [1].

Fig 2.1 shows the radiative forcing contributions of the major greenhouse gases and aerosols that humans have added to the atmosphere since 1750. Fig 2.2 shows a map of the world depicting fires seen from space by the NASA MODIS Satellite during a 10 day period in May of 2019. Such slash-and-burn fires are a significant reason why grazing lands, which constitute 37% of the ice-free land area of the planet only store 2% of the land carbon.

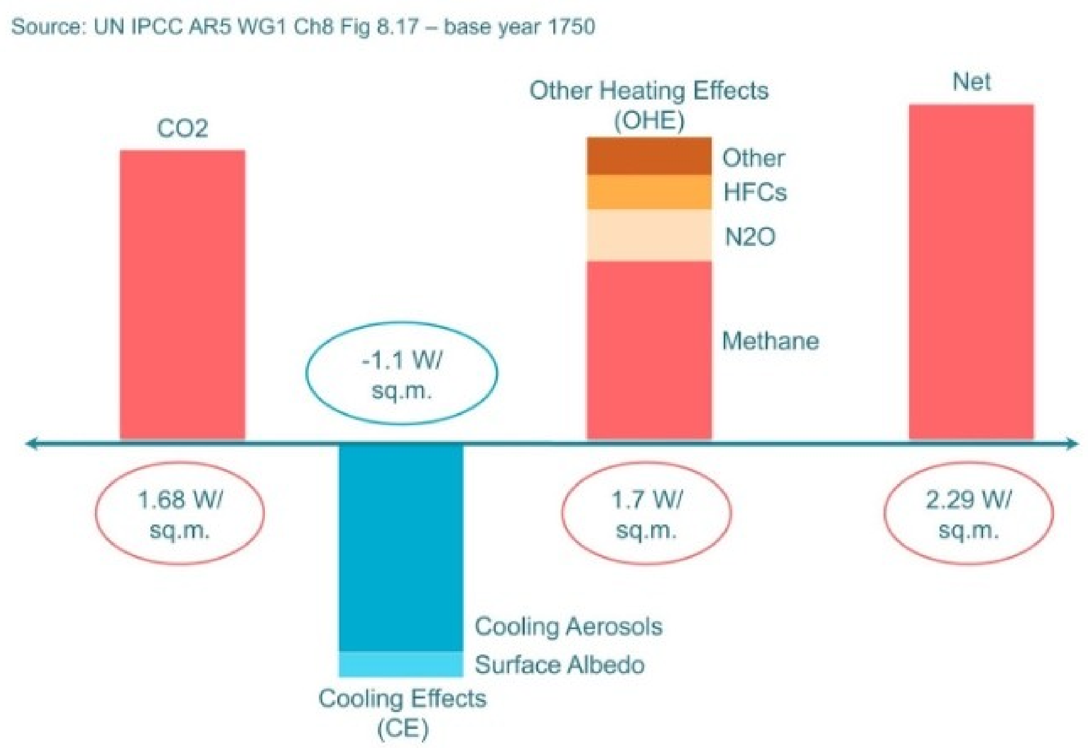


Fig. 2.1. Anthropogenic Radiative Forcing from various greenhouse gases and aerosols, broken into three grouped segments: 1) $CO_2$, 2) Cooling effects such as sulphate aerosols and changes in surface albedo and 3) Other Heating Effects such as methane, Nitrous Oxide, Halocarbons, etc. Values sourced from IPCC AR5 WG1 Chapter 8.

CO2 is absorbed by trees and plants during photosynthesis and it is stored away permanently in vegetation and soil in regenerating forests. However, in the absence of active reforestation efforts, CO2 is a long-lived greenhouse gas that lingers in the atmosphere for tens of thousands of years. At present, about 85% of human-made CO2 emissions are from burning fossil fuels, i.e., coal, oil and natural gas. The remaining 15% is mainly from burning down forests to clear land, i.e., land-use changes[8].

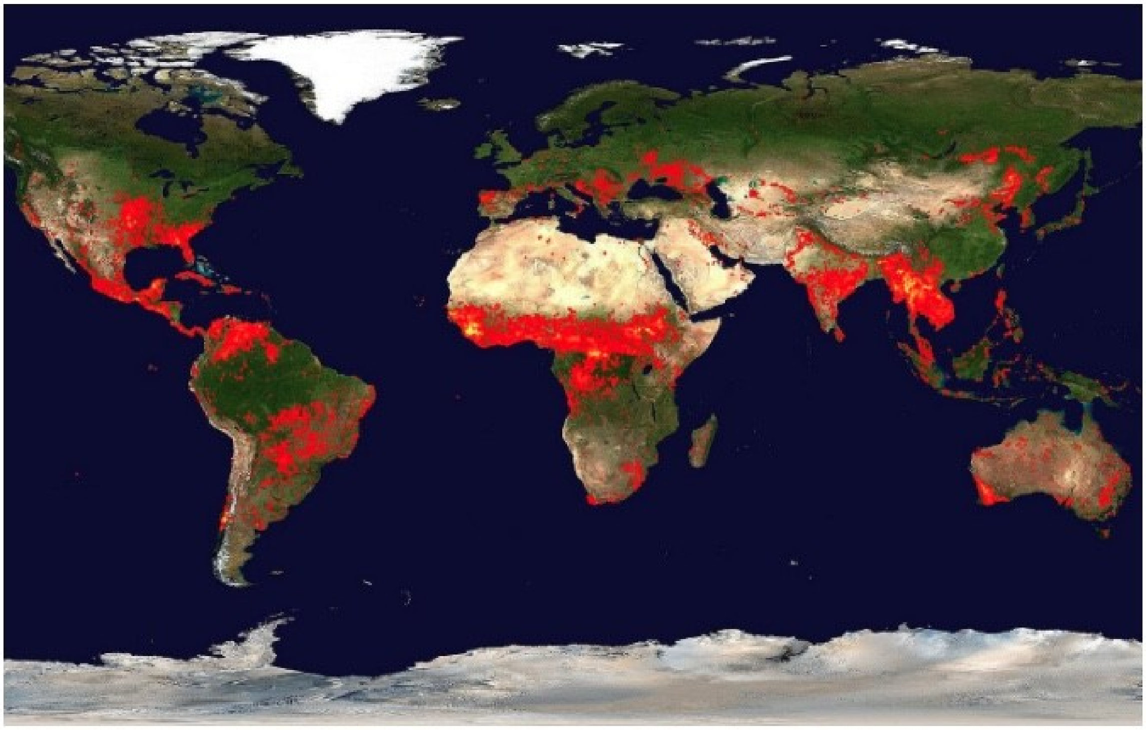

Fig 2.2 NASA MODIS Satellite map of fires that occurred in a 10-day period in May 2019. Most of the fires are human caused, primarily to clear land for animal agriculture.

However, since CO2 is a long-lived greenhouse gas, it is the cumulative emissions of CO2 over time that impacts its radiative forcing, not current emissions alone. In 1850, land use changes were the main source of human-made CO2 emissions, while at present, it is fossil fuels (see Fig. 2.3). Integrating the annual CO2 emissions components over time, we see in Fig. 2.4 that between 1850 and 2011, cumulative CO2 emissions due to land use changes is second only to that from coal burning. Besides, land use changes have been occurring for over 8,000 years, whereas fossil fuel burning only started in the industrial era, around 200 years ago. Since the long-range time constant of CO2 rock weathering sequestration is on the order of tens of thousands of years, it is relevant to consider the cumulative CO2 emissions from land use changes over the past 8000 years. Kaplan et al. has estimated the CO2 emissions due to land use changes in the pre-industrial era to be 1250 Gt CO2[9]. This implies that if we integrate from 8000 years ago to 2011, CO2 emissions from land-use changes is 1850 Gt CO2, which exceeds the CO2 emissions from all fossil fuel sources combined of 1200 Gt CO2. Therefore, land use changes are the leading cause of human-made CO2 emissions over the years and not fossil fuel burning.

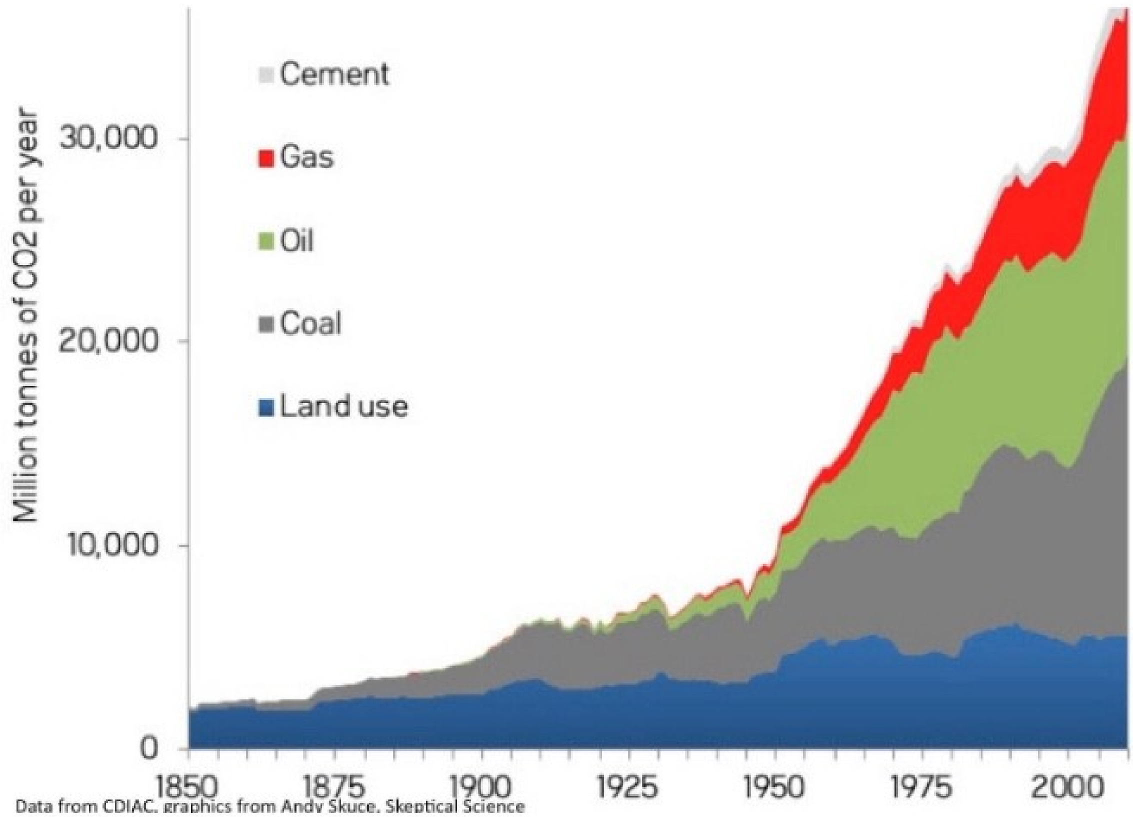


Fig. 2.3. Annual anthropogenic $CO_2$ emissions from Land Use Change + Coal + Oil + Gas + Cement production. Please note that the Land Use Change component dominated in 1850 while the fossil fuel components dominate at present

In summary, of the top three human-made exhaust gases and particles impacting climate change,
1) Land use changes, primarily for agriculture, is the leading cause of CO2 emissions, a global heating component with the largest radiative forcing;
2) Animal agriculture is the leading cause of methane emissions, the global heating component contributing the most incremental heating on an annual basis; and
3) Fossil fuel burning is the leading cause of sulphate emissions, a global cooling component.

With the exception of sulphate aerosols, which are mainly a byproduct of fossil fuel combustion, the other two exhaust gases causing climate change - CO2 and methane - are molecular forms of carbon. Therefore, let us now take a closer look at how humans have altered the carbon composition of the planet.

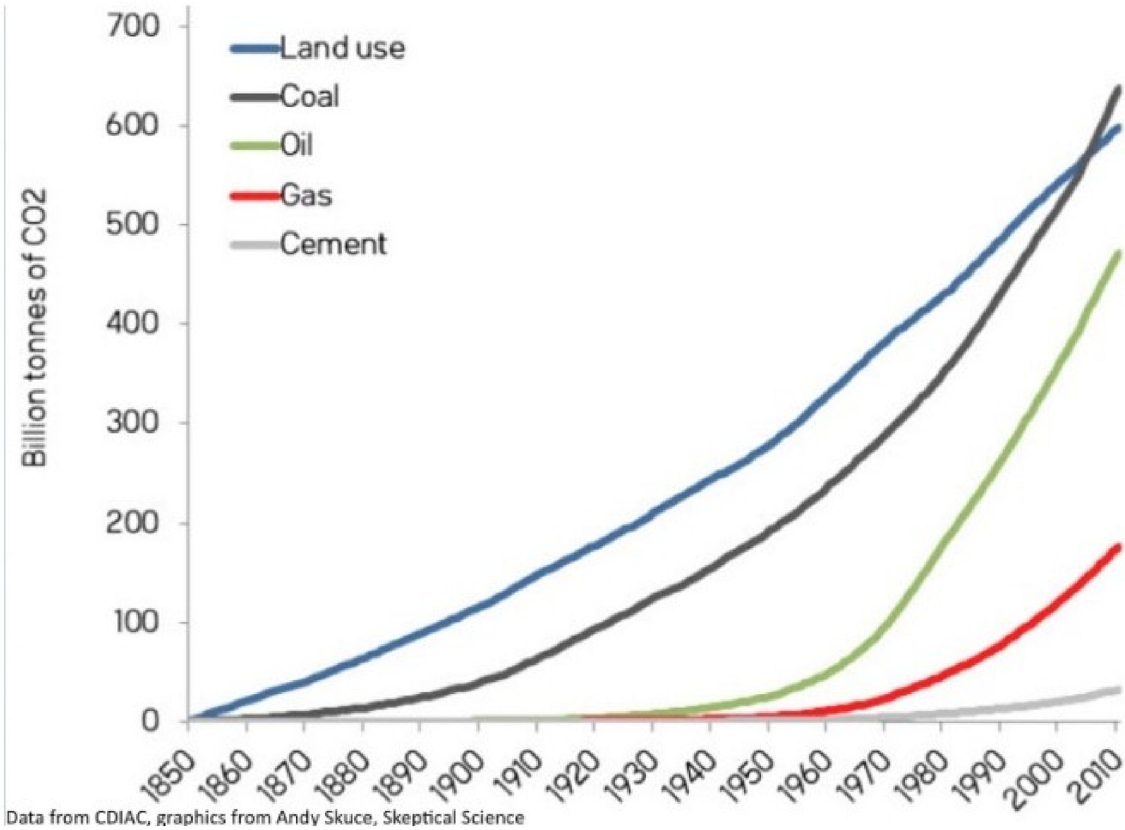


Fig. 2.4. Cumulative $CO_2$ emissions from Land Use Change, Coal, Oil, Gas and Cement production from 1850 onward. Kaplan et. al. estimate the Land Use Change contribution prior to 1850 to be 343GtC or 1260 Gt $CO_2$.

## 3. How Humans Changed Carbon

Carbon is stored on land in vegetation and soils. Roughly half the weight of a tree is carbon. Half the weight of a tree is below ground and half above ground and therefore, the above ground weight of a tree is a good measure of the amount of carbon stored by the tree. In general, soil contains three times as much carbon as the vegetation it holds. Soil carbon excludes carbon stored in trees, plants, animals, birds and insects.

Carbon is stored deep underground in the form of fossil fuels. It is also stored under permafrost land in the form of ancient vegetation that got frozen and preserved at the dawn of the ice ages 3 million years ago.

Carbon is stored in the ocean in surface, intermediate and deep sea sediments. It is also stored in the ocean as dissolved carbon. Finally, carbon is found in the atmosphere, primarily as $CO_2$, methane, organic carbon and black carbon.

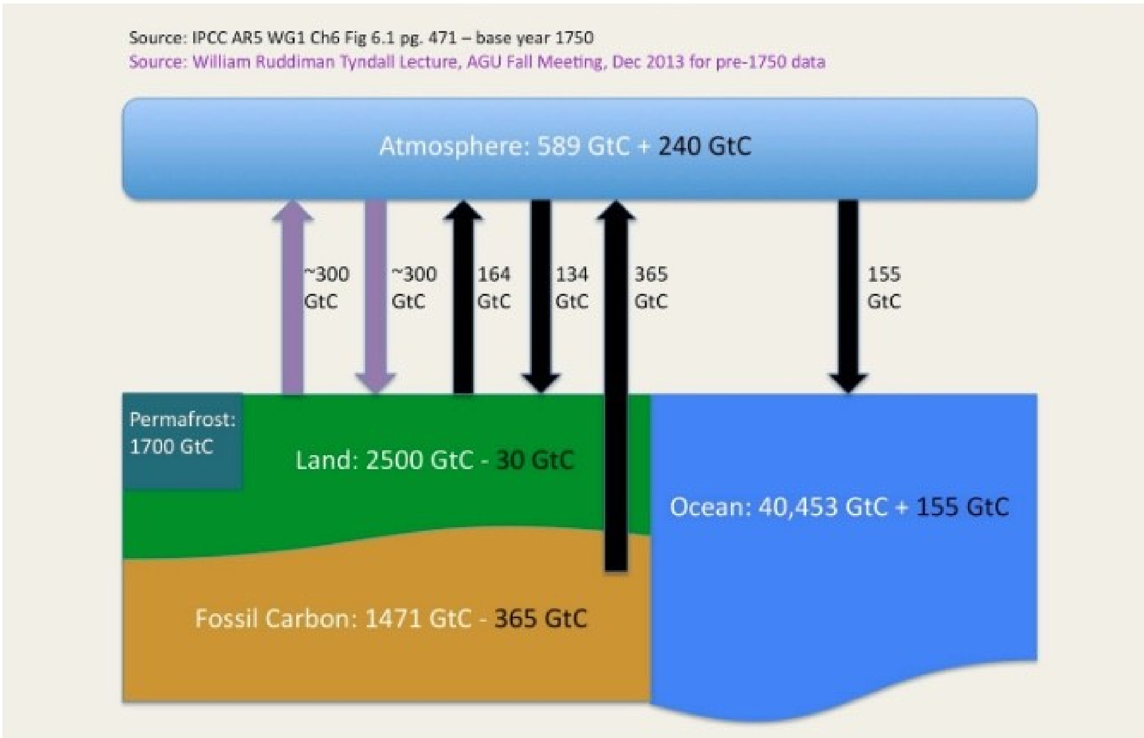


Fig. 3.1. Carbon storage in permafrost, land, ocean, fossil reserves and the atmosphere in 1750 (in white) and the changes since then due to human activities.

For at least 8000 years, humans have been displacing carbon by clearing land for agriculture and by burning fossil fuels (see Fig. 3.1). Most of that displaced carbon has returned back to land, while some has dissolved into the ocean and 240 GtC of it has remained in the atmosphere in the form of greenhouse gases causing climate change. It is estimated that in the pre-industrial era, humans displaced around 300 GtC of carbon on land, but this barely made a dent in the atmospheric CO2 levels as most of it returned back to land in the form of Arctic peat moss, which is a large absorbent moss that grew in the Arctic tundra on boggy ground. Since then, humans have combusted 365 GtC of carbon from the planet's fossil reserves and displaced 164 GtC from vegetation and soil on land. Of that total of 529 GtC of carbon, 45% or 240 GtC has remained airborne in the form of CO2, methane, etc., in the atmosphere, while 155 GtC has dissolved into the ocean and 134 GtC has returned back to land[11].

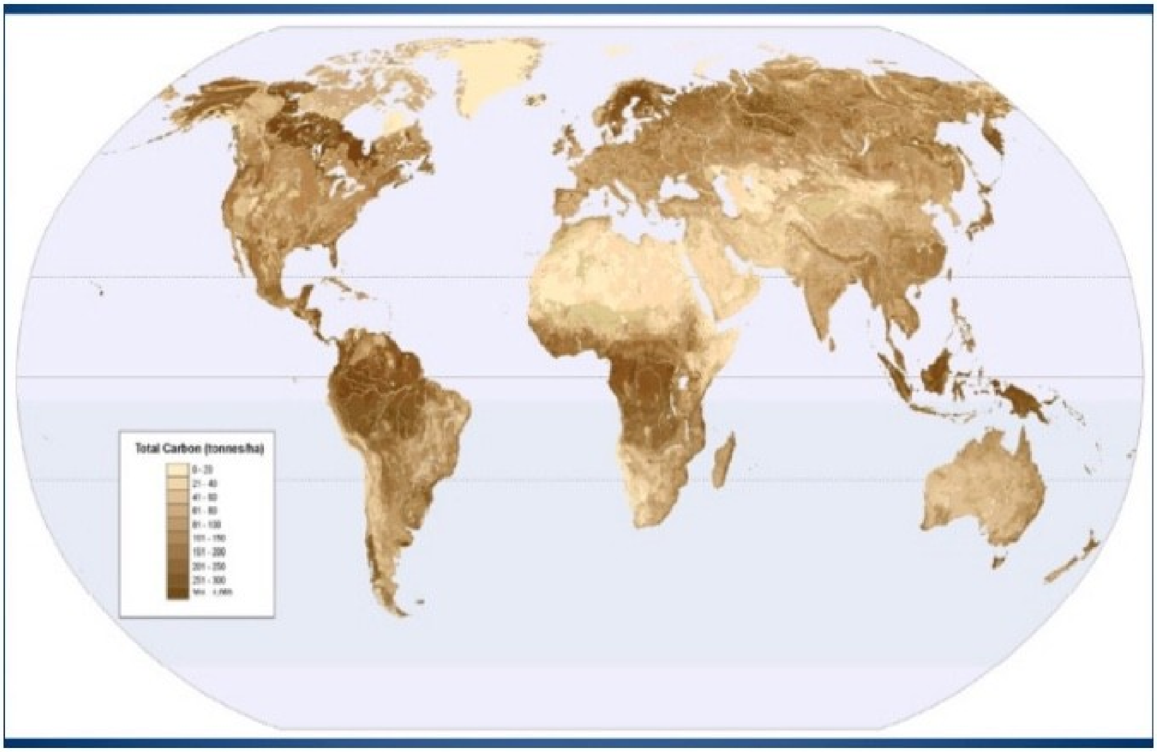


Fig. 3.2. The distribution of carbon on land is highly uneven. The density of carbon is highest in forests and lowest in grazing lands and deserts.

Humans have cut down about 46% of the trees on land since the dawn of civilization[12]. This corresponds to displacing an estimated 464 GtC from vegetation and soils and sending it up into the air. While the pre-industrial clearing of land was compensated by carbon storage in Arctic peat moss, the industrial-era clearing has been mostly compensated with additional storage in forests due to the so-called CO2 fertilization effect[13]. Since the land clearing in the industrial era was accompanied by fossil fuel burning, it raised the atmospheric CO2 levels, which spurred plant-growth due to more efficient photosynthesis. Therefore, even though the cleared land is storing very little carbon as we shall see below, the remaining forests now have a greater density of carbon than in pre-industrial times, which partially offsets the carbon lost due to land clearing.

At present, 2470 GtC is stored in 130 Million square kilometers (Mkm$^2$) of the ice-free land area of the planet, for an average carbon storage density of 19,000 tons per sq. km (t/km2). According to the IPCC Land Use Block diagram (see Fig. 11.9, page 836), 46 Mkm$^2$ or 35% of that land is used as grazing land for animal agriculture[14]. The Integrated Science Assessment Model (ISAM) at the University of Illinois estimates that this grazing land is currently storing 53 GtC, for an average of 1,150 t/km2, or just 6% of the global average[15]. This is reflected in the global land carbon stock map of Fig 3.2, which shows vast swathes of the planet with low carbon density corresponding to where human and farmed animal population is dense.

# 4. Sensitivity Analysis for Human Activities Causing Climate Change

In the previous sections, we have established that land clearing, primarily for Agriculture, and fossil fuel burning are the two main human activities causing climate change. In this section, we will compare the climate change impact of eliminating fossil fuel burning with the impact of eliminating animal agriculture, a sub-sector of agriculture.

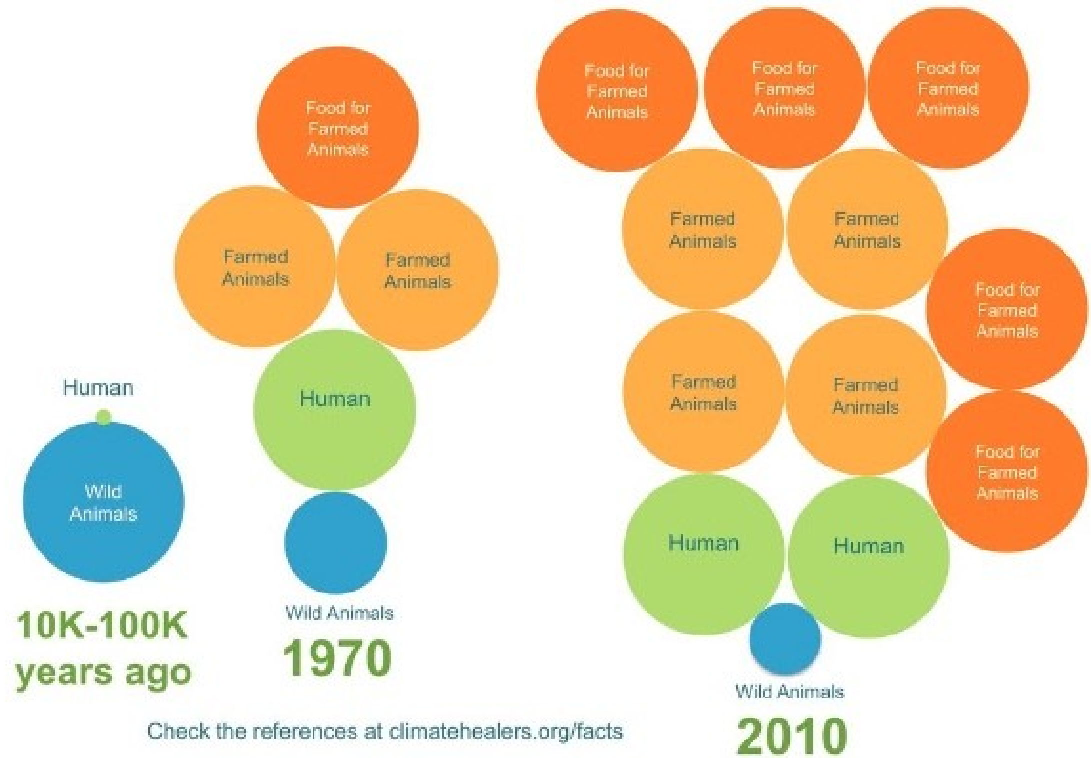


Fig. 4.1. The biomass of wild animals, humans and farmed animals over time. Human biomass was negligible compared to that of wild animals 10K years ago. Today, this biomass ratio is inverted and biomass levels are unsustainable.

At the dawn of the Agricultural revolution, 10,000 years ago, human biomass was negligible compared to the biomass of "megafauna", which are large wild animals that are greater than 44kg in average weight. At that time, humans could afford to lead a predatory existence, cooking and eating animal foods (see Fig. 4.1)[16]. However, in the industrial era, by 1970, human biomass alone was equal to the biomass of all megafauna from 10,000 years ago. In addition, humans were now farming animals whose total biomass was roughly double that of humans, but who were consuming three times as much food as all humans, in terms of dry weight. As far as the planet was concerned, our farmed animals were presenting the profile of a biomass that was triple the biomass of all the megafauna from 10K years ago. Meanwhile, the biomass of megafauna had declined by 60%.

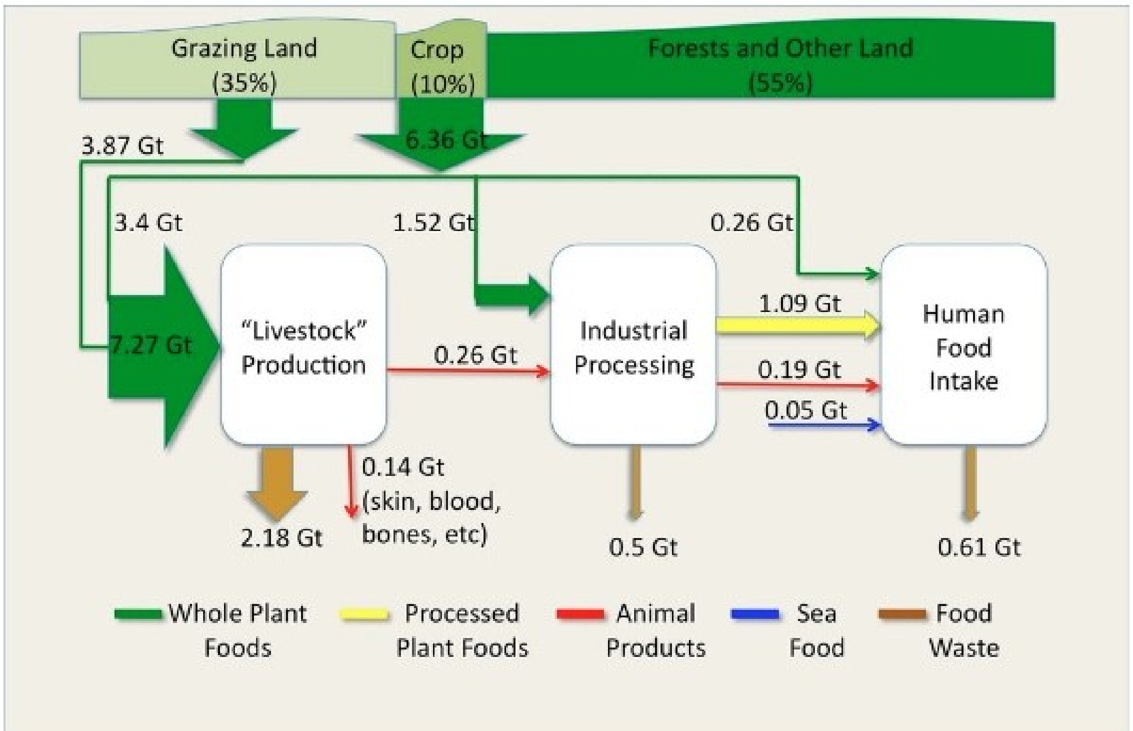


Fig. 4.2. Biomass flows, in Gigatons of dry matter biomass per year, through the Animal Agriculture sector, showing how "Livestock" are consuming 4.5 times as much food as all humans. Source IPCC AR5 WG3 Chapter 11, Fig 11.9, page 836.

Fast forward another 40 years and by 2010, human biomass had doubled from 1970 levels. Our farmed animals were now eating 4.5 times as much food (in terms of dry weight) as all humans thereby presenting the profile of a biomass that is NINE times the biomass of all large wild animals from 10,000 years ago[14], even though their actual biomass is only four times the biomass of all large wild animals from 10,000 years ago. This is because we have genetically selected our farmed animals for freakish characteristics that make them eat more than double what their biomass alone would indicate, on average. For example, the average white rhinoceros weighs 5100 lbs and eats 120 lbs of grass a day. In contrast, the average dairy cow weighs 1700 lbs and eats 140-150 lbs of feed a day.

The biomass of wild animals had declined by 52% from 1970 levels and therefore down by 81% from 10K years ago[17]. The decline in the biomass of wild animals was also accelerating exponentially to be 58% from 1970 levels by 2012[18] and 60% by 2014[19]. The primary driver for this decline is human land clearing for agriculture, since 80% of mass extinction is due to habitat loss[20].

In terms of dry matter biomass, our "livestock" or farmed animals consume more than 80% of the food that we extract from the planet in order to provide just 15% of the food (including "seafood") that humans consume (see Fig. 4.2)[14]. Therefore, plant-based food comprises 85% of the food we eat, in terms of dry weight. Poore and Nemecek have calculated that plant-based foods provide 82% of the calories and 63% of the protein that we consume[21]. Therefore, it is not too far-fetched to ask the question, how much can we mitigate climate change if we eliminated the animal agriculture sector altogether and relied entirely on plant-based foods and products? Indeed, this is a much more immediate, practical scenario than eliminating fossil fuel burning altogether. Of course, this would require us to not use animal products for any purpose whatsoever, i.e., to adopt a "VEGAN" lifestyle, since at present, the animal agriculture industry is providing 190 million tons of "food" for human consumption along with 140 million tons of "other raw materials" such as skin, blood and bones. If we only change our diets, but continue to purchase leather and other animal products, the industry is perfectly capable of raising animals just to produce the "other raw materials" and therefore, we would not be making much of a dent in our environmental impact.

In its Fifth Assessment Report, the UN IPCC had calculated that the "Agriculture, Forestry and Land Use" (AFOLU) sector was responsible for 12 Gt CO2e or 24% of the global greenhouse gas emissions by industry sector, including indirect emissions from the electricity and heat production sector (see Fig. 4.3)[1]. Since animal agriculture is a sub-sector under AFOLU, its contribution must be strictly less than 25%. In contrast, fossil fuel burning was calculated to produce 32 Gt of CO2 or 65% of the total greenhouse gas emissions (49 Gt CO2e) in 2010. Therefore it is tempting to conclude that eliminating fossil fuel burning is a more effective climate mitigation strategy than eliminating the animal agriculture sector.

However, this is like inferring the Earth is flat based on local, line-of-sight observations. Such "Local Sensitivity Analysis" can be notoriously misleading. Firstly, the above comparison is based on current emissions and not on cumulative emissions or radiative forcing, which are more appropriate for measuring climate change impact. Secondly, the IPCC is using a 100 year time frame for calculating the CO2 equivalence of methane, which undercounts its more relevant 10-year impact by nearly a factor of 5. Thirdly, it is not just greenhouse gas emissions, but also aerosol cooling effects that need to be taken into account for comparing climate change impact. Fourthly, the IPCC is allocating each molecule of emission to one sector alone. Therefore, if a truck is transporting agricultural products, its emissions are being assigned to the transportation sector and not to the AFOLU sector. Finally, the UN IPCC is relying on the UN Food and Agricultural Organization (FAO) for its AFOLU data, while the FAO has publicly partnered with the International Meat Secretariat and the International Dairy Federation to promote intensive "livestock" farming (please see Appendix below for a detailed analysis of the IPCC's miscalculations). How reliable can the FAO's analysis be, when it is wedded to industry interests? Indeed, here's a timeline of events debunking the FAO's reports:

## Timeline of Events:

**2005** - Alan Calverd, an independent physicist, published an estimate of GHG emissions from "Livestock" breathing alone is 8.8 Gt CO2e or 21% of total. "Livestock" breathing is a proxy for the avoided carbon sequestration while consuming animal products[22].

**2006** – FAO published Livestock's Long Shadow (LLS) calculating lifecycle emissions from the "Livestock" sector to be 7.5 Gt CO2e or 18% of total, i.e., less than the breathing contribution alone[5].

**2009** – Goodland and Anhang, two Environmental Assessment (EA) specialists with the World Bank, published the WorldWatch report correcting errors in LLS and calculating lifecycle emissions of the "Livestock" sector to be 32.6 Gt CO2e or 51% of total. This 32.6 Gt CO2e can be split into actual emissions of 21.1 Gt CO2e plus avoided carbon sequestration of 11.5 Gt CO2e (see Table 4.1) on the land that would be freed up when animal agriculture is eliminated[3]. The latter is their estimate of the "Carbon Opportunity Cost (COC)" of animal agriculture, to use the terminology of Searchinger et al. In the former, Goodland and Anhang used a 20-year timeframe for averaging the impact of methane instead of the 100 year timeframe used in the FAO's analysis[4].

**2011** – FAO scientists published critique of Goodland and Anhang's estimate in Animal Feed Science and Technology (AFST) Journal[23].

**2012** – Goodland and Anhang published refutation in AFST Journal and reiterated their estimate. FAO scientists declined to continue the debate despite AFST Editor's invitation[24].

**2013** – FAO publicly partnered with International Meat Secretariat and the International Dairy Federation and published revision to LLS, calculating lifecycle emissions of the "Livestock" sector to be 7.1 Gt CO2e or 14.5% of total, without addressing any of the errors pointed out in Goodland and Anhang's report or in the ensuing peer-reviewed debate[2].

Therefore, relying on the FAO's analysis is like relying on a Philip Morris scientific paper that extols the cancer healing benefits of smoking Marlboro Lights[25]. Or the Philip Morris study conducted by Arthur D. Little which found that smokers' early mortality and cigarette-tax revenue outweighed the costs of health-care and lost tax revenue from early death. In its lifecycle analysis of animal agriculture, the FAO had calculated the COC of animal agriculture, i.e., the carbon sequestration that will occur annually if the products of animal agriculture are replaced with plant-based alternatives, to be precisely ZERO. This is incorrect, since animal agriculture is using 37% of the land area of the planet for just grazing alone and this grazing land is storing just 2% of the land carbon[2]. This shows that there is a tremendous dearth of carbon in grazing lands, which is an opportunity to redress the carbon imbalance between land and the atmosphere. Indeed, it appears that Goodland and Anhang may have also vastly undercounted the COC of animal agriculture since they only included CO2 stored in above ground vegetation and did not include CO2 stored in soil. Searchinger et al. calculate the COC to be an average of 5 tons of CO2 per person per year, which works out to a total of 34.5 Gt CO2 for a human population of 6.9 billion in 2010[4]. Therefore, the true lifecycle emissions of animal agriculture is at least 55.6 Gt CO2e in 2010, i.e., **87%** of the total. The detailed calculations are shown in Table 4.1 below:

**Table 4.1:** Percentage contribution of animal agriculture to total emissions in 2010
(UN FAO uses GWP100 of 25 while other columns use GWP20 of 72 for Methane)

| | UN FAO | | Goodland and Anhang | | White Paper | |
|---|---|---|---|---|---|---|
| CO2 | 7% | 2.595 Gt | 29% | 11.5 Gt | 29% | 11.5 Gt |
| Methane | 37% | 2.685 Gt | 37% | 7.732 Gt | 37% | 7.732 Gt |
| Nitrous Oxide | 65% | 1.82 Gt | 65% | 1.82 Gt | 65% | 1.82 Gt |
| COC | | 0 Gt | | 11.5 Gt | | 34.5 Gt |
| Total | **14.5%** | **7.1 Gt** | **> 51%** | **32.56 Gt** | **> 87%** | **55.6 Gt** |

In contrast to "Local Sensitivity Analysis," a "Global Sensitivity Analysis" works by considering the thought experiment: how will the human-caused radiative forcing change in the two scenarios:
a) **Clean Energy Economy:** if we eliminate fossil fuel burning and replace it with clean energy sources, keeping all else the same vs.
b) **Plant Based Economy:** if we eliminate the animal agriculture sector and replace it with plant-based sources, keeping all else the same?

In the Clean Energy Economy scenario, we assume that all energy sources have been transitioned to clean, zero emissions sources, but we will be continuing to burn down forests to grow more animal foods as before. Therefore, land use change emissions would continue to add CO2 to the atmosphere. The CO2 component of the radiative forcing would continue to increase but at a slower pace than before. Since we are no longer burning coal and oil, sulphate aerosols would disappear within 3-5 days, which means that the net radiative forcing would increase by 0.95 W/m$^2$ due to this component. Finally, Other Heating Effects would remain the same so that the net radiative forcing would increase to 3.24 W/m$^2$ from the present 2.29 W/m$^2$, exacerbating numerous catastrophic climate feedback loops.

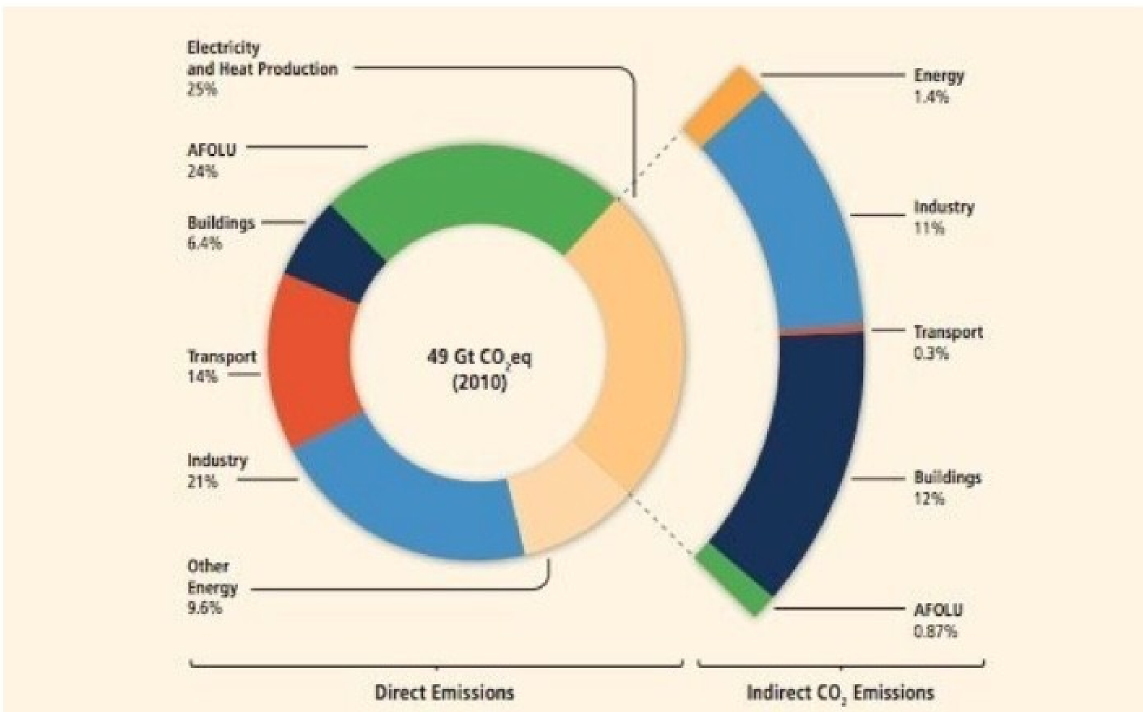


Fig. 4.3. Global emissions by economic sector according to the UN IPCC AR5. Agriculture, FOrestry and Land Use (AFOLU) comprise just 24% of the total, but this fraction doesn't include indirect emissions from transport, industry and other sectors.

In the Plant Based Economy scenario, we assume that all animal products have been replaced with plant-based equivalents and that animal agriculture has been eliminated, but we continue to burn fossil fuels as necessary. From Fig. 4.2, we see that we can now supply all the plant-based food and product requirements from the cropland output alone, freeing up the grazing land for reforestation and carbon sequestration. This grazing land will begin sequestering 34.5 Gt CO2 per year, reducing CO2 levels in the atmosphere. In addition, a good chunk of the fossil fuel burning would disappear as we reduce our need for transporting vast amounts of food to animals, killing them in industrial settings, refrigerating their carcasses, treating diseased people, etc. About

40% of the methane in the atmosphere would disappear in 10-12 years, reducing the radiative forcing by 0.4 W/m2. Therefore, we can expect the net radiative forcing to decrease to 1.3-1.7 W/$m^2$ from the current 2.29 W/$m^2$ within 10-12 years. As the net radiative forcing decreases, we can start gradually switching out the fossil fuel infrastructure for clean energy sources without exacerbating catastrophic climate feedback loops.

The choice between these two scenarios should now be obvious. This shows that animal agriculture is indeed the leading cause of climate change.

As the detailed calculations in Fig 4.4a show, a total shutdown of the Burning machine in the Clean Energy Economy scenario would result in a net **increase** in radiative forcing of 0.901 W/$m^2$ annually. In contrast, Fig 4.4b shows that a total shutdown of the Killing machine in the Plant Based Economy scenario would result in a net **decrease** in radiative forcing of 0.104 W/$m^2$ annually.

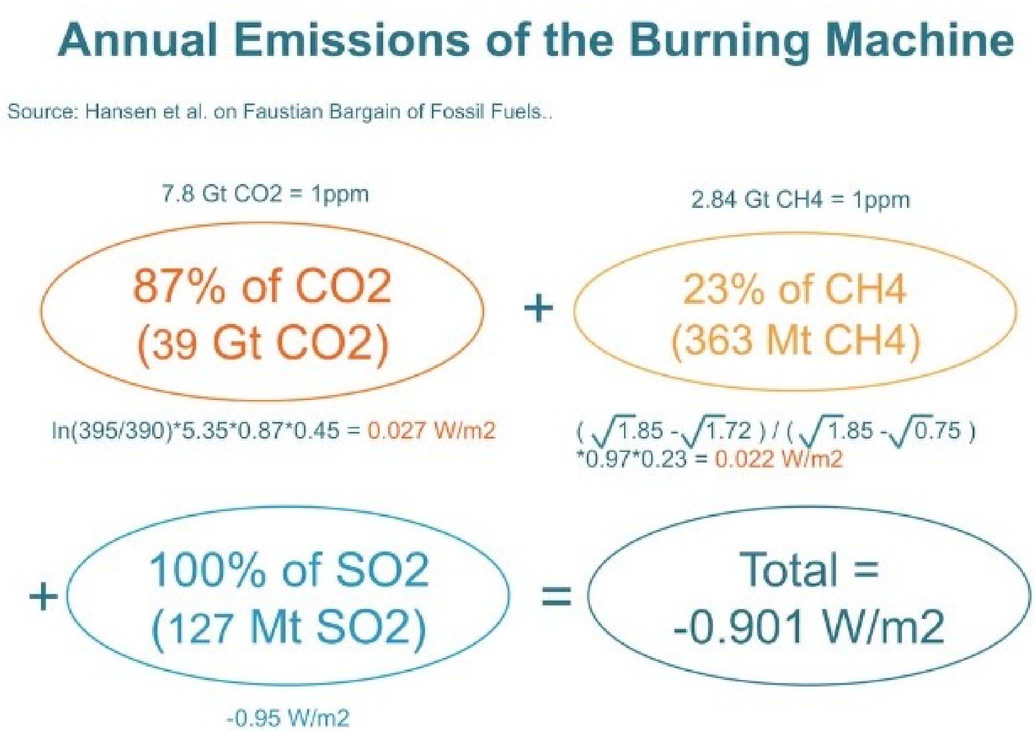


Fig 4.4a: Detailed calculations on the annual change in radiative forcing if the Burning machine is shut down, including CO2, Methane and SO2, while neglecting the impact of other minor greenhouse gases.

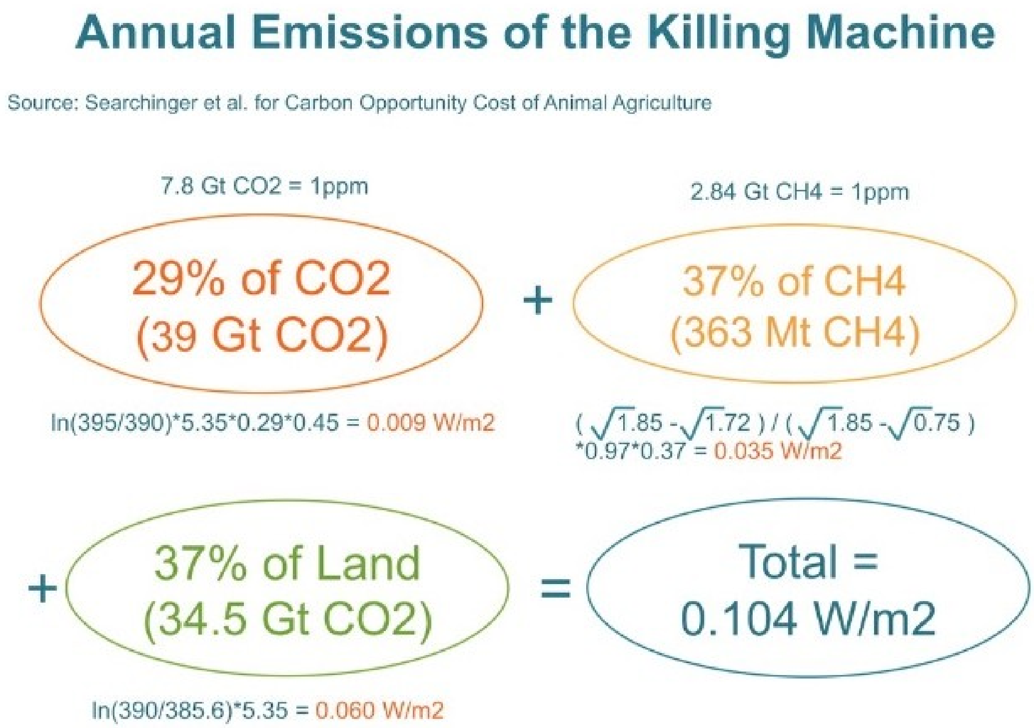


Fig 4.4b: Detailed calculations on the annual change in radiative forcing if the Killing machine is shut down, including CO2, Methane and Land Use changes, while neglecting the impact of other minor greenhouse gases.

Therefore, the optimum strategy to shut down these two machines without increasing the radiative forcing is to first shut down the Killing machine as soon as possible and then shut down 0.104/0.901 = 11.5% of the Burning machine every year for the next 9 years.

## 5. $CO_2$ Sequestration Potential in a Plant-Based Economy

At present, grazing lands store just 6% of the carbon per unit area when compared to the average for all land. In our Lifestyle Carbon Dividend poster paper presented at the AGU Fall Meeting in 2015, we reported that 41% of this grazing land used to be forests in 1800 and that if we can return the original forests on that land, the carbon storage on land would increase by 265 GtC from its present value[15]. Our analysis was conducted using 2014 [HYDE land use data](), assuming that grazing land is reverted to native biomes that existed in 1800[26].

Here are the supporting calculations and extrapolations assuming that all grazing land can be regenerated to store the same carbon sequestration per unit area as the reverted lands:

Total area of grazing lands in 2014: **47.3 M $km^2$**
Total carbon stored in that land (soil + vegetation): **52.8 GtC**
Carbon sequestered per unit area in grazing lands: **1,116 $t/km^2$**
Total area of grazing lands reverted to forests: **19.6 M k**m$^2$
Carbon sequestered in reverted lands at maturity: **292.7 GtC**
Carbon sequestered per unit area at maturity: **14,930 $t/km^2$**
Potential Carbon sequestration in all lands at maturity: **706.2 GtC**
Net Carbon sequestration in all lands at maturity: **653.4 GtC**
Net CO2 sequestration in all lands at maturity: **2396 Gt CO2**

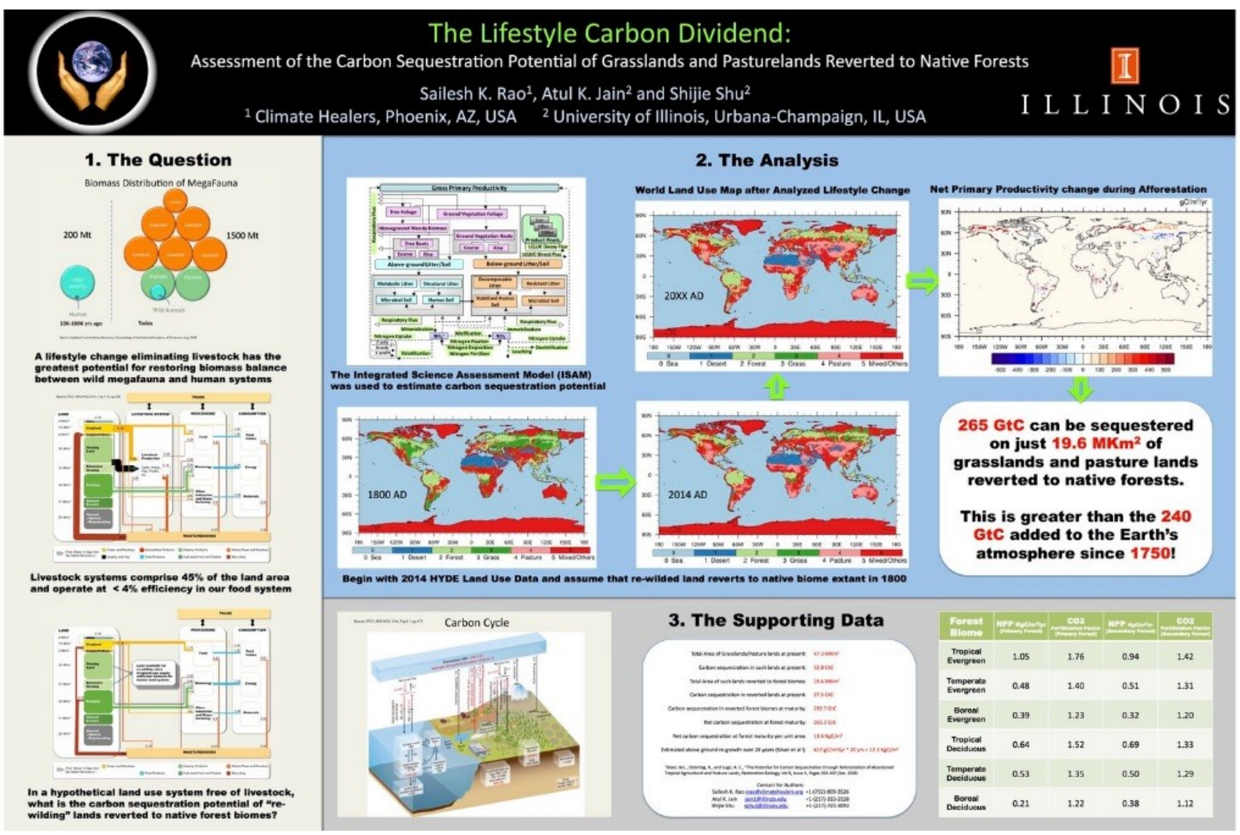


Fig. 5.1. The Lifestyle Carbon Dividend analysis showing that a global transition to a plant-based economy can sequester 265 GtC on just 41% of the grazing land.

Please note that as CO2 sequestration occurs on such a massive scale, we can expect the ocean to release its dissolved CO2 and the CO2 fertilization effect to decrease on land. Then the potential $CO_2$ sequestration will also decline proportionally, because we would be literally reducing the $CO_2$ levels in the atmosphere, a desirable outcome for humanity and all life.

## 6. Conclusions

In this paper, we established that animal agriculture is the leading cause of climate change accounting for at least 87% of annual greenhouse gas emissions. We also illustrated the need to properly sequence the shutdown process for the killing machine (animal agriculture) and the burning machine (fossil fuel burning) so that we don't increase the radiative forcing unnecessarily. Fortunately, this proper sequencing of the shutdown of the killing machine and the burning machine with the attendant global transition to a plant-based economy can be achieved through concerted, grassroots action, with or without the active cooperation of governments, scientific institutions, corporations and the news media.

## Appendix: Four Miscalculations in IPCC Reports

In this appendix, we identify four miscalculations in the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) reports, which cause a systematic under-estimation of the impact of animal agriculture on climate change. For reference, we will use the data in Table SPM1, page 9, of the 2019 IPCC Special Report on Climate Change and Land[6], since it was published after the IPCC had warned humanity in 2018 of potentially catastrophic climate change by 2030, 11 short years from now[7].

The two biggest greenhouse gas contributors to climate change are carbon dioxide ($CO_2$) and methane ($CH_4$). Fossil fuels such as oil, coal and natural gas, produce $CO_2$ when burned. Animal agriculture produces methane gas through farm animals like cows. The IPCC has encouraged the public to focus on fossil fuels rather than animal agriculture, even though methane causes more global warming than $CO_2$ on an annual basis. Here's how:

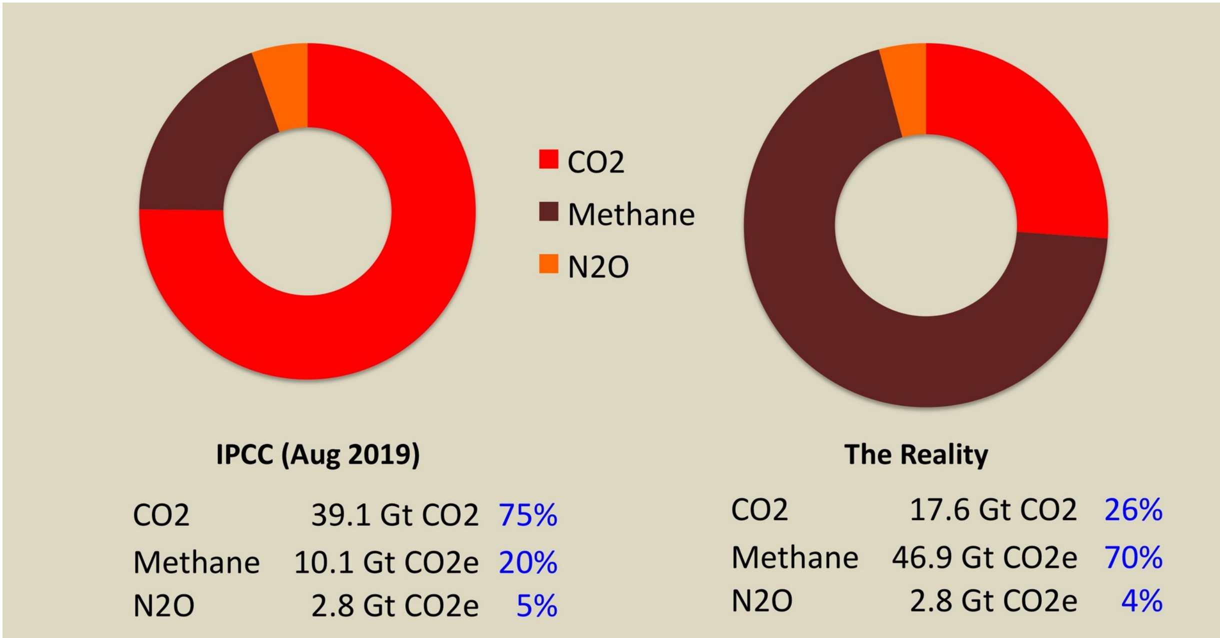


Fig. A.1. A comparison of how the IPCC calculates annual greenhouse gas emissions (see Table SPM1, page 9 of the 2019 IPCC Special Report[2] ) and the reality of how the same annual greenhouse gas emissions impact climate change.

## 1. The IPCC uses total $CO_2$ emissions instead of airborne fraction (45%)

The IPCC counts all human $CO_2$ emissions as contributing to climate change even though less than half of this $CO_2$ remains in the atmosphere as a warming gas on an annual basis. That miscalculation means fossil fuels are being blamed for more than their fair share of climate change, while animal agriculture is not getting the attention it warrants.

In Table SPM1, page 9, of its Special Report[6], the IPCC counts 39.1 Giga tons (Gt) as the average annual $CO_2$ emissions between 2011 and 2016. National Oceanic and Atmospheric Administration (NOAA) Mauna Loa data reveals that between Jan 2011 and Jan 2016, the $CO_2$ levels in the atmosphere increased by 2.24 ppm per year[27].

Each ppm of $CO_2$ in the atmosphere corresponds to 7.81 Gt $CO_2$[28].

Therefore, 2.24 ppm of $CO_2$ corresponds to 17.6 Gt $CO_2$, which is only 45% of the average annual emissions reported by the IPCC.

Hansen et al report that this “airborne fraction” has been decreasing since 2000 even though the rate of $CO_2$ emissions has been increasing. This contradicts the IPCC’s implicit assumption that the airborne fraction is entirely due to land/ocean uptake of past CO2 emissions.

The fact is that human CO2 emissions is occurring on top of a natural photosynthesis and respiration CO2 cycle that is 20 times larger and it is bad science to simply assume that this natural cycle is “perfectly” balanced. This leads one to question how perfect is this “perfect” balance? Is it 99% balanced? Or is it 99.9% balanced?

The IPCC is also simply averaging the CO2 impulse response from different climate models instead of resolving why some of these CO2 impulse responses are so dramatically different.

The lack of inquiry by the IPCC into potential imbalances in the natural CO2 cycle and the poor methodology that it is using to compute the atmospheric CO2 impulse response shows that the IPCC is not too concerned about accuracy in its science so long as it is erring on the side of over counting the impact of fossil fuels and under counting the impact of animal agriculture.

## 2. The IPCC measures the impact of methane over a 100 year timeframe, thereby diluting it, instead of measuring it over a decade

The IPCC underestimates the impact of methane gas by using a timeframe of 100 years. This ignores the fact that methane decays into less harmful CO2 with a half-life of 8.4 years. By stretching methane’s impact over an entire century, the IPCC is diluting the global warming damage methane does on an annual basis, compared to C02. This is like eating a whole cake in one day, each and every Sunday, and then calculating the impact it would have on our body as if we ate it over the course of a year.

In Table SPM1, page 9, of its Special Report[6], the IPCC counts the average annual emissions of methane to be 363 Mega tons (Mt). Over a 100 year time frame, excluding climate carbon feedbacks, this works out to an equivalent CO2 emissions of 10.1 Gt CO2e, using a Global Warming Potential (GWP) of 28. This is the value shown in Table SPM1.

However, over a 10 year time frame, including cloud effects, the GWP of methane is 130, which means that 363 Mt of methane contributes 46.9 Gt CO2e[10].

Please see Fig A.1 for the dramatic impact that the first two miscalculations have on the annual greenhouse gas emissions contribution of CO2 and methane and how it changes the framing of climate change.

## 3. The IPCC does not consider the opportunity cost of land use for animal agriculture

Most forests are destroyed to create animal grazing land. When forests vanish, so does the ability of that piece of land to cool the Earth because trees absorb carbon dioxide and the trees are gone. So, the cooling opportunity is lost. Over time, the absence of those trees means a continuous cause of climate change. Currently, 37% of the ice-free land area of the planet is used for animal grazing, but this grazing land only stores 2% of the carbon on land (see Fig A.2). Yet, the IPCC does not consider the opportunity cost of this land use for animal agriculture.

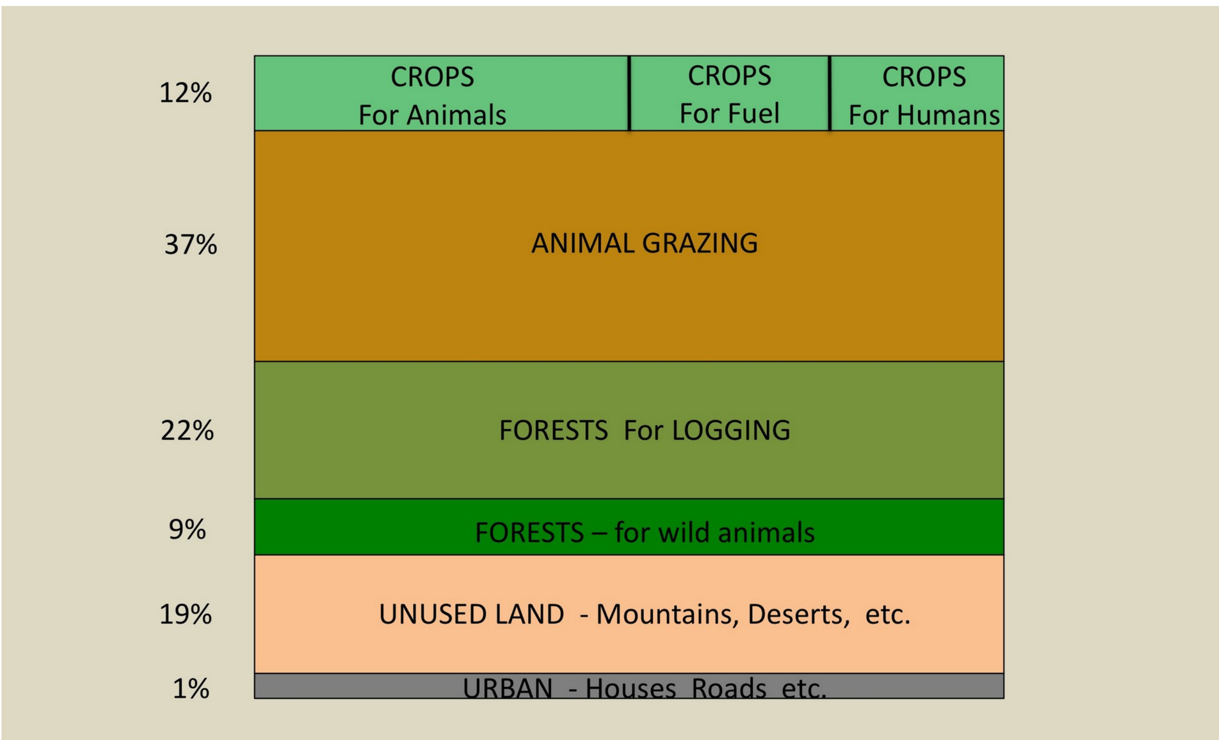


Fig. A.2. How the ice-free land area of the planet is distributed for different uses. Please note that pristine forests constitute just 9%, while Animal Grazing occurs on 37% of the land area. *Source:* 2019 IPCC Special Report[6].

## 4. The IPCC uses raw data from the animal agriculture industry

The IPCC uses raw data from the animal agriculture industry through the United Nations Food and Agriculture Organization (FAO), instead of neutral sources. This is like getting our data from the tobacco industry to determine cigarettes impact on health. The UN FAO has a public partnership with the International Meat Secretariat, International Dairy Federation and the International Egg Producers Association, all industry promotion organizations. Members of the UN FAO are co-authors of IPCC reports, thereby eliminating any semblance of neutrality in the IPCC's scientific deliberations on the impact of animal agriculture.

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