LETTERS

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# Effect of Dietary Adjustment and Afforestation on Global Temperature Change

**The International Panel on Climate Change (IPCC) has determined that anthropogenic activities have had a clear influence on observed temperature changes. Rise in global temperature has had intense impacts globally and action must be taken now to prevent continued temperature rise in the future[1]. Substantial co-benefits stand to be had through adaptive agricultural practices and the protection of carbon storage ecosystems, like forests[1]. Based on the growing popularity of dietary change and the high potential of carbon sinks formed through afforestation, the simple model used here projects a future in which tropical livestock agriculture is halted and the livestock land is used for carbon sequestration through afforestation[1,2,3,4,5]. This scenario is run in four different economic situations: User (USE), fossil fuel intensive (FF), convergent (CON), and business as usual (BAU). 41% of the initial carbon emission alterations from livestock agriculture eradication and intense sequestration through afforestation produced a temperature change range of 3.1° to -5.6°C. Projections were also run to assess the effect of different climate feedback parameters (Y) on temperature change induced by tropical livestock agriculture eradication alone and in combination with sequestration under USE conditions. Variations in Y (0.9, 1.3 and 2.3 $Wm^{-2}$/K) produced a temperature change range of 2.9° to -4.9° K**

Up to 14% of global GHG emissions are from agriculture and 77% of those emissions come from livestock[1,2,3]. Afforestation is one of the most viable adaptive measures for carbon sequestration[1,4]. Current research also shows that the energy use and GHG emissions of plant-based diets are less than that of standard meat-based diets and every year larger numbers of people adopt vegetarian and vegan lifestyles[5]. Assuming the movement to plant-based diets continues to increase, it will be possible to remove livestock agriculture from parts of the globe. Those lands could then be used for afforestation in order to increase sinks for carbon absorption from the atmosphere[1,6]. This transition to afforestation has estimated costs that are much lower than for other carbon removal technologies like carbon capture[7]. It has been found that carbon sequestration from intense afforestation could potentially capture up to 860 $GtCO_2$ by 2100[6]. However, afforestation has the potential of huge social impacts such as an increase in global food prices that can lead to competition between agriculture (other than livestock) and afforestation. If afforestation was unrestricted, food prices could increase up to 80% by year 2050. However, when restricted to only tropical regions, food prices peak in 2075 and then decrease and so stay much lower[6]. The tropical region is also best suited for this land use transition as studies have shown that transition to forest in these zones can result in intense cooling while afforestation in other zones could result in less change or in some cases, warming[8]. By restricting afforestation to the tropical regions to minimize social and financial implications and to attain the highest cooling effect, 525 $GtCO_2$ can be absorbed by 2100[6].

To create a scenario where livestock agriculture is reduced and replaced by afforestation with minimal effect on social and cultural norms, emissions of livestock from only the tropical region of the world (between 20°N and 20°S) were removed from annual global emissions in these projections. Tropical

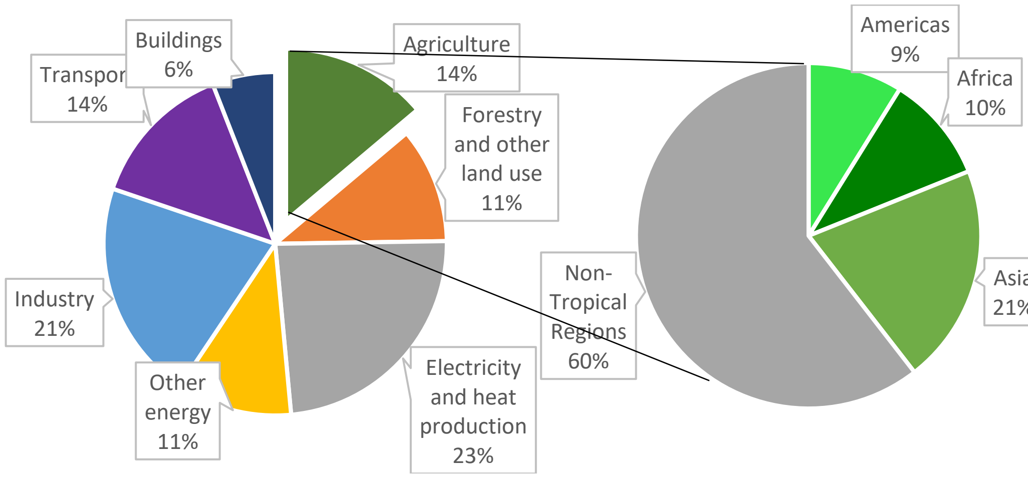


**Figure 1: Contribution of GHG by sector and contribution to agriculture GHG by sub region of global**

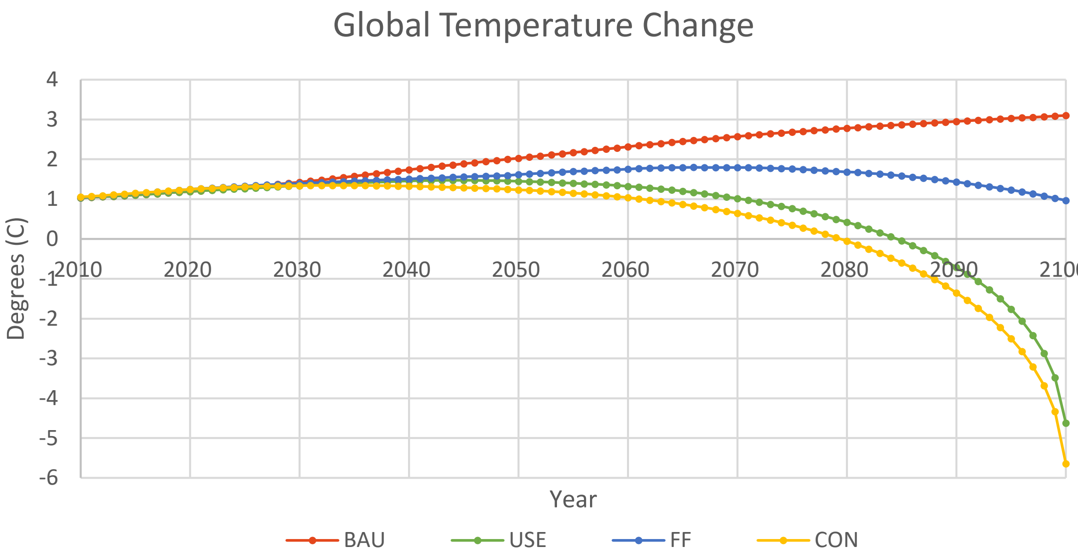


**Figure 2: Global temperature change projections with eradication of livestock agriculture coupled with intense afforestation in only tropical regions. Projected under 4 economic conditions: BAU (no change from current emissions), USE (BAU combined with carbon emissions calculations), FF (a fossil fuel intensive world), CON (climate change mitigation and adaptation greatly increased).**

agriculture emissions account for 40% of total agriculture emissions (Figure 1) and removing 77% of those emissions effectively simulated the stopping of livestock agriculture in the tropical regions. The annual amount of carbon sequestered per year to reach 525 $GtCO_2$ through afforestation by 2100 was then removed as well. The emissions were not completely removed until year 2020 to allow a small transition window. This was done under all economic conditions. As the conditions projected were too high for the climate model to calculate temperature change, 41% of the calculated values were projected to year 2100. As seen in Figure 2, in all but one economic condition, with 40% global livestock agriculture removed and the land then used for afforestation, global temperature change does not exceed the Paris Agreement goal of 2°C temperature change by the end of the century[9]. This includes FF, a condition which pushes for the increased use of fossil fuels. Under BAU conditions, however, temperature increase reaches above 3°C but under USE and CON conditions, the global temperature change becomes negative. These stark contrasts in the temperature changes illustrate what large roles the economies and cultures of the world will play in climate change mitigation and adaptation.

Scenarios were also created in which livestock production in the tropics was removed and no afforestation occurred. It was found that this scenario did not produce temperature changes within the realm called for by Paris and Kyoto etc. under any of the economic conditions. The viability of this outcome was then tested using multiple Climate Feedback Parameters. In accordance with the IPCC report, the initial Climate Feedback Parameter (Y) value used was 1.3 $Wm^{-2}/K$ [12]. Y simulates how reactive the planet is to forcings. That is, Y has a direct effect on the Equilibrium Climate Sensitivity (ECS), or the sensitivity of the earth to changes in the forcings. With a small Y, the ECS is larger and this slows down response time to forcings. Conversely, with a large Y, the ECS is smaller and the response time speeds up. Projections of only tropical livestock agriculture termination with the standard Y value of 1.3 $Wm^{-2}/K$ showed temperature change by 2100 was well above the 2°C aim.

Two additional Y values were then set, both within the IPCC range of 0.8 – 2.4 $Wm^{-2}/K$. Table two shows the relationship of Y to overall temperature change through to 2100. When Y is set to 0.9 $Wm^{-2}/K$ the temperature increase hits almost 3°C. However, when Y is increased to 2.3, the temperature change at the end

**Table 1: Global temperature change (°C) assuming varied Climate Feedback Parameters. USE Livestock = scenario with tropical livestock agriculture halted. USE Livestock & Sequestration = scenario with tropical livestock agriculture halted and replaced by afforestation.**

| | *0.9 Wm-2/K* | *1.3 Wm-2/K* | *2.3 Wm-2/K* |
|---|---|---|---|
| *USE Livestock Only* | 3.7765 | 2.9969 | 1.9678 |
| *USE Livestock & Sequestration* | -4.9092 | -4.6195 | -3.9493 |

**Table 2: Generated amounts of carbon (PgC) sequestered from the atmosphere through afforestation in tropical regions by year 2100.**

| | ***USE*** | ***FF*** | ***CON*** |
|---|---|---|---|
| *Livestock Only* | 11.68782 | 27.03366 | 4.63944 |
| *Livestock & Afforestation* | -133.096921 | -117.751081 | -140.145301 |
| *41% Livestock & Afforestation* | -54.5697377 | -29.4377703 | -57.4595735 |

of the century is 1.9°C, hitting just below the limit set by climate scientists and policy makers (Table 2)[9].

Though the negative temperature changes in Figure 2 show climate target potential, these amounts of sequestration are not realistic as the time for land transition is not accurately accounted for in this model and sequestration from afforestation will not take full effect for a decade or so[11,13]. The sequestration averages used in the model are also based on a study where there is an exponential tax on $CO_2$ emissions for the lands used for afforestation [6]. This tax would not exist under FF conditions and cannot be accurately programmed into the model under the other conditions. Afforestation sequestration numbers also vary according to study year, area and author. For example, in 1995, Nilson and Schopfhauser concluded that by 2095 104 GtC would be sequestered given a global afforestation initiative which is a stark contrast to the possible 860 $GtCO_2$ which Kreidenweis and Humpedoder (2016) consider possible[6,11,13]. This sequestration scenario is also unrealistic in that eradicating 40% (Figure 1) of the livestock sector from the globe would take decades, if it even happened. Other social issues must be taken into consideration as well. For example, nations losing this sector will potentially need to import meat for consumption which will increase emissions and food prices. Free trade agreements may assist in mitigating initial price shocks and cultural transition effects, but policies surrounding these types of market-based incentives are difficult to achieve on a global level as they are often voluntary and so inconsequential when ignored[6,9,10].

The model also overlooks the effects of these adaptation measures on local populations. As used, this climate model does not correct for albedo change from afforestation. Studies have shown that albedo effects from land use changes have the capacity to negate carbon sequestration on the local level even though regionally or globally carbon is being captured via afforestation. The local effects of changing temperatures are often more intense and important than the global temperature shift, especially in a scenario like this in which those most affected are in tropical regions where seasons are intense and time-specific[14]. As the model projects only global temperature changes, the regional and national effects of climate and temperature change cannot be accounted for and so are more difficult to consider in policy making.

Aside from cultural and societal issues, the climate model itself is limited in ability and this makes it difficult to project future temperature changes. For example, as demonstrated by varying the Y values, temperature change is dependent on how reactive the earth is to the forcings. Climate science is not exact and so cannot project how reactive the planet will be to forcings in the future[1]. Therefore, the most that can be deduced from these findings is that, under the scenario described, there is a possible global temperature change range between 3.1°C and -5.6°C. Additionally, as the model is based on the findings of Le Quéré, it assumes that 43% of $CO_2$ emissions will remain in the atmosphere[15]. The issue here is not necessarily in the percent of carbon assumed to remain in the atmosphere. It is instead with the fact that the carbon sink does not fluctuate in the model. The same amount of carbon is not kept in the atmosphere every year or every day and so to project for the future as if that were the case produces uncertainties in the data.

Moreover, this model is only capable of handling carbon emission numbers within a certain range. As mentioned before, the actual calculations for how much carbon was taken from the atmosphere through livestock agriculture eradication coupled with aggressive afforestation were extremely negative. The model could only cope with calculating the forcings based on 41% of the original calculations. Table 2 shows the real calculations in total PgC that would have been removed by 2100 had the model been able to use that data.

The climate model for these projections is too simple to account for regional albedo costs, changing atmospheric carbon sinks or extremely negative emission numbers. The numbers it produces are extremely negligible which makes them very hard to use in policy making decisions.

Despite these restrictions, however, the data outputs from the projected scenarios bare an amount of truth. Afforestation is already known to be one of the most affordable carbon sequestration tools currently being tested. Even at 41% of the original values calculated, the global average temperature projected for 2100 was well below 2°C. Considering other effects not included in the model, such as changes in the atmospheric carbon sink, potential increased fossil fuel emissions (coal mining and oil drilling are still huge sources of energy), and other sources of increased emissions and heat absorption that are not included in this model, it is likely that, though afforestation in tropical regions does have a large cooling effect, the temperature change would not be as intense as portrayed here. Even without afforestation, however, a change in global dietary needs has the potential to shift global temperature down. The possible temperature decrease from removing 40% of world livestock agriculture would keep the globe right under the 2°C limit on a moderately reactive planet with a Y value of 1.3 $Wm^{-2}/K$.

These results can be used to further research on this and other subjects pertaining to matching the global temperature change limits set by the Paris Agreement[9]. As more people move to animal-based diets yearly and the world becomes more aware of the implications attached to global temperature change, there could be real potential for a scenario related to this projection to occur. While these number are obviously skewed and very optimistic, they can certainly pave the way for new studies on lifestyle and land use change and the real impacts they can have on the climate.

**Methods**

A simple climate model was used to produce temperature change projections to the year 2100. The model assumed a 43% retention of $CO_2$ in the atmosphere annually and was based on the model set out by Hansen et al, 1981[4,15]. The model calculated radiative forcing from the annum carbon emissions and then derived annual temperature change accordingly.

Numbers for global and national agricultural emissions for 2005 were gathered and sorted into regions[16]. Data was used from 2005 as that was the last year input into the climate model used. 77% of tropical agricultural emissions were then removed from the projected yearly carbon emissions successively to 2100. Similarly, projected numbers of carbon sequestration from afforestation to 2100 were attained and then divided into annual subtractions. The annual sequestration amounts were then removed from the annual carbon emissions as well.

This was done from year 2020 to year 2100. A two-year gap was given from present to the start of the modelling to account for part of land use change and other adjustments. The initial final emissions values were too negative to be used by the model. The numbers were then reduced to 41% of the original, at which point the model could project temperature change with them. The amounts were removed from all economic scenarios: BAU, USE, FF and CON. The resulting temperature changes were then taken from the 'Climate Model' tab and plotted to show projected temperature change across economic conditions for the same scenario.

Similar projections were made under varying Climate Feedback Parameters (Y). The initial Y value under which all projections were run was 1.3 $Wm^{-2}/K$ in accordance with the IPCC report[12]. The Y values were then varied to 0.9 $Wm^{-2}/K$ and 2.3 $Wm^{-2}/K$ and scenarios under the USE conditions were run for only livestock agriculture mitigation and livestock agriculture mitigation combined with intense afforestation. The final global temperature change values were then placed in a table for analysis.

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