EVALUATING THE USE OF CARBON OFFSETS IN IPCC 1.5℃ WARMING SCENARIOS

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Executive Summary:

The world faces the daunting task of limiting global warming to 1.5 degrees Celsius. Integrated Assessment Models help us understand pathways to achieve this goal in the most efficient way. In most scenarios where the international community can limit warming to 1.5℃ carbon dioxide removal is deployed to help reach net-zero emissions targets by sequestering carbon through land-based sinks like afforestation and reforestation or technology like bioenergy or carbon capture & storage. Therefore, it is theoretically important that the international community uses available forms of carbon sequestration, specifically readily available ones like terrestrial carbon offsets, carefully to offset emissions from difficult to decarbonize industries like aviation, steel production, and ferrous metals. As a key part of emissions reductions strategies, using carbon offsets for anything but offsetting emissions that cannot readily be decarbonized theoretically risks our ability to meet reduction targets. This MP seeks to examine data from Integrated Assessment Models and how they use carbon offset credits to limit warming to 1.5℃ and study the carbon offset credit market in the real world to identify purchasers and find out whether offsets are being used in the most efficient way.

Objectives:

The objectives of this study are fourfold. Analyze emissions and carbon sequestration data from IPCC scenarios in the IAMC 1.5℃ Scenario Explorer; analyze the compliance and voluntary carbon offset markets for evidence and patterns in the use of offset credits; compare the deployment of Agriculture/Forestry/Other Land Use (AFOLU) CDR in Integrated Assessment Models to current offset market trends to establish a gap in efficient use; and establish policy recommendations for using offset credits.

Methods:

Of the 177 scenarios in the IAMC Scenario Explorer, 75 of them limit global temperature increase to 1.5℃. 74 of those scenarios employ carbon dioxide removal in some way. The method in this study was to focus primarily on scenarios with a “land-use change” variable in their underlying data, as the study focuses on carbon offsets through AFOLU carbon dioxide removal rather than BECCS or other methods. From the underlying data for these scenarios we pulled out, cleaned, and calculated CO_2 emissions, residual positive CO_2 emissions, N_2O emissions, carbon capture and storage, and carbon sequestration from land-based sinks. These variables gave us the information needed to establish the average Gt/year of CO_2 the scenarios were sequestering through land-based sinks, and if that amount was enough to offset emission from difficult to decarbonize industries.

Thes study also used data from the European Emissions Trading System. Variables in the underlying data included the carbon offsets traded in a two-year period, what economic sector the offset was being employed by, and the total CO_2 emissions from each sector. This allowed us to determine that

carbon offsets, at least in Europe, are largely being used by the power sector for electricity generation and other processes, rather than airline fuel, steel production, or other industries. For the voluntary market, a literature review on relevant information was conducted and we were able to establish the largest institutional purchasers of offsets and what they were offsetting when making those purchases.

Findings and Results:

The study found that the average yearly residual positive emissions that need to be offset is about 10.3 Gt/CO_2 per year in the data subset where both the land-use change variable and N_2O emissions were accounted for. According to the 2020 Production Gap Report sponsored by the UN environment program, the feasible amount of CDR available each year around 2050 is only 8.6 Gt/CO_2 per year. This confirmed our theory that all available offsets for carbon dioxide removal must go directly to offsetting the dirtiest industries or we risk being unable to meet warming targets.

The study also found that in practical use, this is not what is occurring. In Europe, more than 60% of carbon offsets are being used to offset emissions from power generation at stationary installations, and none of the top five corporate purchasers of carbon offsets are from the difficult to decarbonize sectors of the global economy. This suggests that there is a sizable gap between what Integrated Assessment Models assume carbon offset credits are being used for and how they are being employed in reality.

Broader Ramifications:

The data from this study suggests a ban on offsets for anything other than offsetting the dirtiest industries must be considered. This could be on an international (Conference of Parties or binding international agreement) or national (federal/state laws). Integrated Assessment Models also should consider accounting for misuse of offsets when calculating emissions targets. Finally, institutional purchasers of offsets should take a hard look at the effects of their purchases. Although it may balance their emissions sheet and provide public relations fodder, in the long run it is a detriment to our collective goal of limiting warming to 1.5℃ .

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Introduction

In 2015, the Paris Agreement was adopted by 196 parties to limit global temperature change to a maximum of 2℃, and preferably 1.5℃. The Intergovernmental Panel on Climate Change published the "Special Report on Global Warming of 1.5℃" (SR 1.5) in 2018 and highlighted the potential benefits of limiting warming to 1.5℃ versus 2℃ or higher (IPCC, 2018).

The Summary for Policymakers version of the report says "Our world will suffer less negative impacts on intensity and frequency of extreme events, on resources, ecosystems, biodiversity, food security, cities, tourism, and carbon removal" (IPCC, 2018). A review of literature on 1.5℃ warming targets published in the Journal *Science* in 2019 calls limiting warming to 1.5℃ a "human imperative" to avoid catastrophic climate damage (Hoegh-Guldberg et al., 2019). Finally, in 2019, the United Nations Environment Programme said the goal of limiting warming to 1.5℃ will "slip out of reach" without drastic CO_2 emissions reductions and that Nationally Determined Contributions (NDCs) submitted under the Paris Agreement leave global emissions 29-32 Gt/CO_2 short of what is needed (Hausfather, 2019). With current NDCs alone not sufficient to limit the world to 1.5℃, different pathways forward must be considered using different economic and policy levers to control emissions. For those pathways forward to effectively meet the 1.5℃ target, SR 1.5 says the planet must reach net-zero CO_2 by around 2050.

Carbon Dioxide Removal:

One tactic for decreasing global CO_2 in the atmosphere is to employ Carbon Dioxide Removal, known as CDR, to remove carbon from the atmosphere using either natural or technological means (Masson-Delmotte et al., 2018). Three main categories encompass the majority of CDR and are broken out into a few major categories.

Bioenergy and carbon capture & storage (BECCS) pull carbon out of the atmosphere. Biomass is grown and acts as a carbon sink, and converted to bioenergy for power. When biomass is used, carbon emission occurs, and carbon capture and storage secures those emissions and cycles them back into the ground. Since bioenergy is a carbon sink as excess CO_2 is captured, using bioenergy produces negative emissions (“Negative Emissions Technologies & Reliable Sequestration”, 2019).

Carbon dioxide removal from fossil fuels is similar to BECCS. Emissions are captured from fossil fuel combustion and stored underground, preventing CO_2 from reaching the atmosphere. Both CO_2 removals from fossil fuel combustion and BECCS are considered by the international community to be extremely expensive to apply at scale (Rogelj et al., 2018).

Under the natural process umbrella is carbon sequestration in soil, afforestation, reforestation, and carbon storage in rocks and oceans. These processes store carbon in natural carbon sinks, rather than creating underground deposits of captured emissions. Already proven to work in nature, increasing the acreage of the forest, changing soil practices, and converting land draw emissions out of the atmosphere, assisting the world in reaching CO_2 reduction targets. This is colloquially known as Agriculture, Forestry, and other Land Uses CDR or AFOLU. One common and well-known way for AFOLU CDR to be applied is through the purchase of carbon offset credits. These are generally measured in metric tonnes of CO_2 and are purchased to offset the emissions produced by an individual, company, or government. Purchases can be voluntary or compliance-based. Voluntary offsets are purchased to offset emissions for public relations, ethical, or economic reasons, while compliance offsets are purchased to meet caps on emissions set by governments, like the European Union's Emissions Trading System.

IPCC Scenario Explorer:

In 2018, the IPCC released a report titled "Special Report on Global Warming of 1.5℃." The report is based on an "ensemble of quantitative climate change mitigation pathways" that were aggregated into the IIASA Scenario Explorer (Huppmann et al., 2019). These pathways take the form of scenarios with a myriad of different focuses, constraints, and conditions. For example, scenarios set carbon budgets, maximum reliance on certain technologies and renewable energy, and enact policy changes like carbon taxes or new international commitments. The scenarios include a range of warming targets, from below 1.5℃ of warming to above 2℃. There are 177 scenarios in the Scenario Explorer.

Each model has run at least one, and usually several, different scenarios. The models are housed at different research institutes and government agencies across the world. Individual models have different objectives and concepts that underpin how they use input data. The concepts vary from economic growth models to market or partial equilibrium and incorporate a simple or detailed climate/energy model. There are 25 models in total. Of the 177 scenarios, 75 of them limit the global temperature increase to 1.5℃ or below.

Study Objectives

Of the 75 scenarios limiting global temperature increase to 1.5℃, 74 of them rely on some form of carbon dioxide removal to reach net-zero or net-negative emissions. With carbon dioxide removal a key part of all relevant scenarios, every potential Gt/CO_2 that can contribute to reduced emissions is critically important. There is between 210-540 Gt/CO2 in AFOLU CDR available globally from 2020-2100 (Rogelj et al, 2018). This finite quantity of CDR limits its ability to aid the world in reaching net-zero.

The scenarios limiting warming to 1.5℃ assume that negative emissions from CDR will offset the most difficult to decarbonize industries, like metal smelting, heavy-duty vehicles, aviation, and a range of material industries. These industries have major challenges with decarbonizing, such as their high dependence upon fossil fuels, known as a carbon “lock-in”, and their lagging behind other industries with technology and feasibility (transport lags one to three decades behind other sectors) (Pietzcker et al., 2014). Rather than employ expensive or unfeasible means to decarbonize these industries, carbon dioxide removal’s negative emissions can make up for the emissions of the “dirtiest” industries and enable the world to reach the net-zero required to stabilize temperatures.

This study challenges the alignment between the application of negative carbon emissions from AFOLU CDR in 1.5℃ scenarios with how they are applied in reality. The theory is that while BECCS remains expensive and unreliable, AFOLU CDR will play a key role in reducing emissions. However, if the majority of purchasers of carbon offset credits have other avenues to decarbonize, like electrification, technological investments, or adjustments in fuel inputs, they are taking away potential emissions reductions from difficult to decarbonize industries. This would create a mismatch between how the scenarios employ CDR and how it is being employed in reality, a discrepancy that is important to study as the global community attempts to limit warming to 1.5℃ above pre-industrial levels. It would also leave a chunk of CO_2 emissions from difficult to decarbonize industries as positive emissions since potential offsets would have been used up by other entities.

Based on the data available through the IPCC 1.5℃ scenarios, and thorough accounting of the current carbon offset credit market, the other core objective of this study is to develop a rubric for potential purchasers of carbon offset credits. The goal is to use the rubric to grade purchases of carbon offset credits and whether they help or harm the global community's push for 1.5℃ of warming.

Materials and Methods

The IAMC 1.5℃ Scenario Explorer hosted by IIASA is the central hub for the aggregated 1.5℃ scenarios. In addition to scenarios for below 1.5℃ warming, some scenarios overshoot then return to 1.5℃ by 2100, scenarios over 1.5℃ but below 2℃ and above 2℃ warming scenarios. The most recent release update was August 8, 2019. Data from the Scenario Explorer is used because it is the only location where this quantity of modeling scenarios is aggregated and made accessible to the public.

Selection & Removals:

Of the 177 scenarios in the Scenario Explorer, 75 of them limit the global temperature increase to 1.5℃ or below. This figure includes "overshoot" scenarios, where the temperature increase exceeds 1.5℃ but then returns and settles at 1.5℃. There are high overshoot and low overshoot scenarios. From there, four scenarios were removed.

- "Ratchet-1.5-limCDR-noOS" was removed due to a lack of scenario documentation
- "Ratchet-1.5-noCDR-noOS" was removed due to a lack of scenario documentation
- "TERL_15D_LowCarbonTransportPolicy" was removed because it deals with a transport-specific policy that is not relevant to CDR use
- "TERL_15D_NoTransportPolicy" was removed because it deals with a transport-specific policy that is not relevant to CDR use

Categorization:

The scenarios are categorized by the primary type of CDR they employ. When looking at the cumulative total amount of CDR in metric tonnes of CO2, each scenario is coded with whichever type of CDR is most prevalent. This includes combinations of multiple types of CDR if no one type made up an overwhelming amount of the cumulative CDR. The categories include fossil fuel, land use, and biomass.

Each scenario also includes a short description either quoted or summarized from the IIASA's "documentation" page as well as a reference for the original published paper that underpins the scenario's context. The full table can be viewed in Figure 1 of the Appendix.

Figures and Calculations:

The figures calculated in the table are fourfold. For all 71 scenarios, cumulative CO_2 emissions (in Mt/CO_2) were calculated for the years 2050-2100. Because most 1.5℃ scenarios reach net-zero around 2050, emissions were calculated for the 2nd half of the century, after the "easiest" parts of the global economy have been decarbonized. Post-2050, the only remaining residual positive emissions would be from difficult to decarbonize industries. Some scenarios had data in five-year increments, others had ten-year increments. To establish a cumulative figure without yearly increments we use linear interpolation between the five or ten-year increments. The formulas used are available in Figure 3 of the Appendix.

The second figures are for cumulative CCS (Carbon Capture and Storage) in Mt/CO_2. CCS is defined in these scenarios as " total carbon dioxide emissions captured and stored in geological deposits (e.g. in depleted oil and gas fields, unmined coal seams, saline aquifers) and the deep ocean" (Huppmann et al., 2019). The same linear interpolation was calculated for five or ten-year increments. Three scenarios, Ratchet-1.5-allCDR, Ratchet-1.5-limCDR, and

Ratchet-1.5-noCDR, did not have CCS data. The biomass variable was substituted for these three scenarios. The biomass variable covers “total CO_2 emissions captured from bioenergy use and stored in geological deposits” (Huppmann et al., 2019).

The final figures are for CDR from land use. This is a separate variable where data was available for 40 of the 71 scenarios. This land-use variable is defined by IIASA as “total carbon dioxide sequestered through land-based sinks (e.g., afforestation, soil carbon enhancement, biochar)” (Huppmann et al., 2019). These figures are in Mt/yr of CO_2 and are reported as positive numbers.

Finally, N_2O emissions data for all 71 scenarios were available from the Scenario Explorer. N_2O accounts for 6% of global greenhouse gas emissions and has 265-298 times the GWP (global warming potential) as CO_2 (“Understanding GWPs,” n.d.). With approximately 75% of N_2O emissions coming from the agricultural sector, it is a difficult GHG to control because it does not have a point source such as emissions from power plants (Chrobak, 2021). In the data table, linear interpolation is calculated for N_2O for five or ten-year increments depending on the data. Data were downloaded in kt/yr of N_2O, which has been converted to CO_2e using a conversion factor of 273. The figures were divided by 1000 to convert from kt to Mt of $CO2_e$ per year.

<u>Data Subset:</u>

A second data set was created to analyze only scenarios where data was provided by the Scenario Explorer for the “land use” variable. As defined in the previous section, scenarios including this variable were put in a separate data set with the same calculations. The intent of subsetting this data is to narrow focus from scenarios that deploy any kind of CDR, which broadly covers the multiple types discussed earlier, and scenarios with a specific and measurable contribution to CDR from afforestation, reforestation, and other land-based sinks (Huppman, et al., 2019). Because of how difficult it is to scale up BECCS besides "various pilot projects and small-scale BECCS projects" and the scientific community's skepticism about BECCS technology ("Fact Sheet: BECCS," 2020), this paper focuses on the land use subset as the set of scenarios most feasible to limit warming to 1.5℃. Although some scenarios in the larger dataset used some sort of AFOLU CDR, to quantify the average yearly carbon sequestration, the land use subset is used.

Results and Observations

For each scenario, two figures represent the residual positive emissions after accounting for land use and carbon capture & storage. Cumulative emissions from 2050-2100 are measured in Mt CO_2 and Gt CO_2 / year and are generally presented as a negative number, as only one of the 71 scenarios has positive cumulative emissions from 2050-2100. The other 70 scenarios are negative. Added to this are carbon reduction from land use and carbon capture & storage. These are reported as positive numbers. By adding these to the cumulative emissions totals, the leftover positive emissions from this calculation are "residual positive emissions." They are emissions that were not reduced in the scenario but because so much carbon was captured or sequestered, the overall emissions balance is net-negative. This is a key feature of nearly all 1.5C-consistent scenarios as these almost always include more carbon emissions through 2050 than the allowable 1.5℃ budget, requiring net negative emissions after that time to achieve the target temperature.

The same process for evaluating residual positive emissions was used for the land use subset. In the land-use subset, every emissions scenario limiting warming to 1.5℃ has negative cumulative emissions from 2050-2100.

Additionally, residual positive emissions for CO_2 and N_2O from 2050-100 are calculated by adding together the residual positive emissions from CO_2 and the cumulative emissions from N_2O. This provides a more complete picture of N_2O's role in limiting global warming, as it is a GHG that is largely ignored and difficult to reduce while providing adequate food for the world's growing population as it largely comes from the use of fertilizer in agriculture. Histograms for the full scenario list and the land use subset are figures 8 and 9 respectively, and both show that the bulk of scenarios has roughly 75-150 Gt of cumulative N_2O from 2050-2100.

Summary Statistics:

Initial results from the full set of scenarios indicate that the average residual positive emissions for CO_2 from 2050-2100 are about 7.3 Gt CO_2 per year. Within the land use data subset, the average is higher at 9.0 Gt CO_2 per year. Unsurprisingly, when adding additional emissions from N_2O, that average increases to 9.3 Gt CO_2 per year for the full dataset and 10.3 Gt CO_2 per year for the land use subset.

The coefficients of variation indicate that there is a relatively high variation for the CO2-only datasets (0.91 for the full list and .88 for the land use subset) and a slightly lower variation for the CO_2+N_2O datasets (0.71 and .80 respectively). The land-use dataset has a higher average of positive residual emissions than the full set of scenarios and the range of values is slightly smaller than in the full dataset. Summary Statistic values are available for reference in Table 1 of the appendix. A histogram of the residual positive emissions for the land-use and full scenario list can be seen in Figure 6 and Figure 7, respectively.

Distributions and Visualizations:

In the appendix are histograms for the preliminary data from the IAMC scenario explorer as well as residual positive emissions for the full data set, the land use subset, and again for both sets with the addition of N_2O emissions. As noted in the summary statistics table, the cumulative residual emissions have a large standard deviation for both sets of data, suggesting a wide range of potential outcomes across the more than 70 scenarios studied here. The majority of the scenarios, however, are concentrated in the range of 250-625 Gt for the cumulative emissions of CO_2 plus N_2O (Figure 11), corresponding to 5.0-12.5 Gt/yr for the most likely range.

Points of Reference:

The values of residual positive emissions from the set of scenarios closely resemble the given value from the 2020 Production Gap Report as the estimated limit on AFOLU and BECCS CDR in the year 2050. They estimate that the total Gt CO_2 per year cannot exceed 5.0 for BECCS, and 3.6 for AFOLU, giving a total allowable CDR quantity of 8.6 Gt CO_2 per year in 2050 ("The Production Gap Report: 2020 Special Report," 2020). This figure is close to the average values for the full dataset of scenarios (7.3 Gt CO_2 per year from 2050-2100) and the land use subset (9.0 Gt CO_2 per year). There is a discrepancy between the two figures, as the Production Gap Report limits are for 2050 and the dataset of scenarios is an average from 2050-2100. However, there will not be a rapid expansion of capacity for AFOLU CDR from 2050-2100.

Looking only at the land-use subset, the total allowable CDR quantity is within .4 Gt $CO_{2,}$ per year of the average amount of CDR used in the 40 land-use scenarios available in the IAMC explorer. This furthers the discussion around how the world should employ carbon offsets to limit warming to 1.5℃.

Before this analysis, it was not obvious that figures derived from the Integrated Assessment Model scenarios would come so close to the figures quoted in the Production Gap Report. The fact that they are within .4 Gt CO_2 is a coincidental finding with substantial implications. It leaves extraordinarily little room for misuse of carbon offsets and suggests that all of our available, verifiable offsets need to contribute to offsetting the dirtiest and most difficult to decarbonize industries, rather than offset power generation, emissions from large corporations, or fossil fuels for vehicles (Lovins, 2021).

These analytical figures stand in contrast to a recent push worldwide for companies to achieve carbon neutrality, where carbon emissions are not increasing and companies are "achieving carbon reductions through offsets" by 2050 or earlier (Bigg, 2021).

Carbon Offset Market Introduction and Analytics

Carbon offset credits are an "accounting mechanism" that allows institutions, governments, or individuals to offset their emissions without making technical or behavioral changes (Irfan, 2020). Instead, parties can pay for emissions reductions or uptake, e.g. by ecosystem restoration or repair effort anywhere in the world, and the additional carbon that the project sequesters from the atmosphere can be counted against their emissions. An example given by a 2020 Vox news article states Jet Blue's effort to have its flights be carbon neutral. Jet fuel has significant carbon emissions; 70% of exhaust emissions from airlines come in the form of CO_2 and are produced at a ratio of 3.16kg of CO_2 per one kilogram of fuel (Overton, 2019). Despite accounting for 2.4% of global CO_2 emissions in 2018 (Overton, 2019), there are efforts to "green" airline fuels, including a plan by plane manufacturer Airbus to produce hydrogen-consuming planes in the next two decades. However, current jet fuel consumption is almost entirely pure petroleum, and even major advances in sustainable biofuels would make little progress. A 2021 study from the International Council on Green Transportation suggests that 5.5% of airline fuel could be from sustainable fuels in the EU by 2030, leaving the vast majority of planes running on petroleum (O'Malley, Pavlenko, Searle, 2021).

In the interim, companies like Jet Blue make offset purchases to reduce their reported CO_2 emissions since viable technology and changes are far away in the future. These are what are known as voluntary offsets. There is no governing body forcing carbon offset purchases on JetBlue, rather they are making a conscious decision to reduce their carbon footprint as a corporate ESG (Environmental and Social Governance Strategy).

Conversely, there are compliance-based trading markets that can be intra-national, international or state/province level in nature. Known as emissions trading systems, or ETS, compliance-based carbon markets seek to reduce CO_2 emissions through a permitting system for tonnes of CO_2, where permits can be traded between polluters. In most ETS structures, carbon offset credits can be purchased to reduce emissions in the form of Emissions Reductions Units (ERUs) or Certified Emissions Reductions (CERs). Each unit is equivalent to about one metric ton of CO_2 (“Finance and Carbon Markets Lexicon,” 2012). A list of active ETS’ and their use of carbon offsets is below (De Clara, 2014 & icap, 2021). The information has been sourced from icap, the International Carbon Action Partnership, and is current as of November 2021.

Country/Province/State	Emissions Coverage	Carbon Offsets
International:		
Kyoto Protocol	N/A	Yes
European ETS	39%	Yes
Western Climate Initiative (California, Quebec, Nova Scotia	N/A	Yes
National:		
Mexico	N/A - Pilot Program	Yes

China	40%	Yes
Germany	N/A	No
Kazakhstan	41%	“Under Consideration”
South Korea	74%	Yes
New Zealand	51%	Yes
Switzerland	10%	Yes
United Kingdom	33%	No
Subnational		
Beijing, China	45%	Yes
Tianjin, China	55%	Yes
Shanghai, China	>50%	Yes
Fujian, China	N/A	Yes
Shenzhen, China	40%	Yes
Guangdong, China	70%	Yes
Chongqing, China	62%	Yes
Hubei, China	N/A	Yes
Nova Scotia, Canada	80%	“Under Consideration”
Quebec, Canada	80%	Yes
RGGI (11 States), United States	N/A	Yes
California, USA	N/A	Yes
Massachusetts, USA	N/A	N/A

Saitama, Japan	N/A	Yes
Tokyo, Japan	N/A	Yes

Each ETS system has varying degrees of allowable use of offsets in the scheme. According to icap, the allowable percentage of total emissions that can be reduced through offsets ranges from 3.3% (RGGI) to no cap at all (Tokyo, but with a 33% cap on foreign offset use). Generally, there is a nationalistic tilt toward offsets; many countries such as the Chinese National ETS only allow for domestic offsets and expressly prohibit the use of foreign or international offsets to reduce emissions within the trading system. The mapping of different ETS systems shows that individual countries and governments have markedly different approaches, but almost every ETS system in existence today will rely on carbon offsets to meet reductions targets.

Compliance Market Overview:

Taking the European ETS system as an example, there is relatively robust reporting data on where CERs or ERUs are being deployed to meet compliance obligations in systems like the EU ETS. The most recently available data published by the EU is for the years 2010-2012. It shows that a total of .9 Gt of CO_2 was used by way of offsets to meet compliance obligations from 2010 to 2012. The majority of this (about .77 Gt CO_2) was used in the combustion of fuels, production of pig iron or steel, production of cement clinker, refining of mineral oil, and the production of lime. This data is available in table 4 of the appendix. The offset data from the EU ETS shows that within their compliance framework, offset credits like CERs and ERUs are primarily employed by manufacturing and industrial companies, as well as fuel combustion operations ("EU Emissions Trading System Data Viewer Background Note," 2021).

Diving further into the data, the background notes published by the European Environment Agency regarding the EU ETS system state that 61% of verifiable emissions from stationary installations come from fuel combustion, which mainly consists of electricity generation (“EU Emissions Trading System Data Viewer Background Note,” 2021). In contrast, cement, clinker, and lime stationary installations account for only 10% of emissions (Ibid). With nearly two-thirds of total emissions coming from fuel combustion, and the more than 60% of offsets used to negate those emissions, carbon offsets are not being deployed to offset difficult to decarbonize installations, but rather to decarbonize the economic sector that is likely easiest, which is electricity generation. In a 2020 report from Mckinsey on pathways for the EU to reach net-zero, they state that because “wind and solar power generation technologies are already available at scale, power would be the quickest sector to decarbonize” (d’Aprile, Engel, Helmcke, et al., 2020). Additionally, an article published in the journal *Nature* found that “solar photovoltaic, onshore and offshore wind can become the cornerstone of a fully decarbonized energy system” and that decarbonizing the power sector will be less expensive than others (Victoria, Zhu, Brown, et al., 2020). Instead, extremely valuable carbon offsets are being used to negate power generation emissions that could be easily decarbonized and deliver “broad economic benefits” (d’Aprile, Engel, Helmcke, et al., 2020).

Outside of Europe, another example of improper deployment of carbon offsets comes from RGGI, the Regional Greenhouse Gas Initiative that covers nine eastern states and aims to “cap and reduce CO_2 emissions from the power sector” (“Welcome,” 2022). Because RGGI is an initiative solely aimed at the power sector, any offsets employed to reach targets are inherently being used to decarbonize power generation. Although power plants can only use offsets to cover 3.3% of their carbon budget (Ibid), these are still valuable offset projects that could be used to offset emissions from dirtier and difficult to decarbonize industries. So far, there is only one operating RGGI offset project as the initiative only allows verified offsets from within RGGI member states. The current active offset generator is a methane flaring project in Maryland that has been operating since 2016 and supplied RGGI with 5,306 credits. Almost half of the participating states do not allow offsets to be used by their power plants to offset emissions. Despite the lack of practical use, RGGI still allows offsets to be used by member states. The design of the system runs contrary to where the world should focus the mitigatory power of offsets.

Voluntary Market Overview:

Establishing a snapshot of the global offset market is difficult as regional ETS systems, voluntary offset purchases, private "over the counter" businesses, and more entities all trade in different systems. Without a unified international trading system, the size and scope of the offset market remain somewhat vague. However, Ecosystem Marketplace (EM), an initiative of the Forest Trends 501c3 non-profit, runs the "world's first and only independent international voluntary and compliance carbon credits trade reporting and knowledge-sharing mechanism" ("About Us," 2021). EM does not claim to completely capture the voluntary and compliance markets but does tout that its survey respondents cover 80 countries, 172 individual projects and developers, and governments. Additionally, the survey has seen marked increases in participation year over year since its inception (Ibid). The publicly available data is most centered around the voluntary carbon credit market. As a function of volume, EM data shows that 19 million tCO_{2e} of offsets were purchased by corporate buyers in the energy sector, while 2 million tCO_{2e} or less were purchased in sectors like consumer goods, finance and insurance, manufacturing, and more ("Volumes and Prices by Buyer Sector," 2021). Through three quarters of 2021 (up to August), the majority of reported volume was purchased by projects in the AFOLU and renewable energy sectors (115 $MtCO_2$ and 80 $MtCO_2$ respectively). The 80 $MtCO_2$ of renewable energy offsets is not relevant to our discussion here because it is assumed that renewables completely replace conventional power generation by 2050 if the world is to limit warming to 1.5℃. These figures account for the reported retirement of offsets upon completion of a project. Of the $MtCO_2$ of AFOLU offsets reported in 2021, about 100 million of those offsets were purchased for REDD+ related projects (“Issuances and Retirements,” 2021). REDD+ is an international effort to “reduce emissions from deforestation and forest degradation” and was developed by the United National Framework Convention on Climate Change. Another 80 million were for non-REDD+ projects.

Consumer and market data firm Statista and reporting from Bloomberg give additional insight into the voluntary credit market. Bloomberg stated in a 2020 article on the redundancy of carbon offset credit schemes for forests that were already protected that companies “are avoiding making necessary eco-friendly changes” and are instead purchasing offset to reduce the carbon balance on “their ledgers” (Richter, 2020). Furthermore, buyers of voluntary credits have moved from making credit purchases to buying entire projects that are set up and verified to issue credits, rather than buying the credits themselves (Favasuli, 2021). This removes the middle-man and allows large companies like Shell to have a direct flow of available offset credits that they can use to balance their carbon budgets, re-sell, or otherwise trade (Ibid).

The largest purchasers of voluntary offsets in recent years are corporations that specifically are not considered the dirtiest emitters, or have particular difficulty decarbonizing emissions. As of 2019, 36% of the companies in the S&P 500 Stock Index were reported to have bought offset credits (Bindman, 2021). The top purchasers are the Walt Disney Company, Microsoft, Salesforce, Goldman Sachs, and Nike, according to the Carbon Disclosure Project (Bindman, 2021). For example, Microsoft committed in 2020 to use offsets to completely erase 100% of their historical, current, and future emissions as a company. Large offset purchases such as this detract from the total amount of verifiable offsets that can help mitigate emissions from difficult to decarbonize industries. The express purpose of companies buying individual offsets is to neutralize their carbon emissions, but an emerging question is being asked; “what would you do if you couldn’t just buy offsets?” (Irfan, 2020).

Discussion

From snapshots of the voluntary and compliance carbon markets, and with the knowledge that many trading schemes cover power generation, which makes up a large percentage of the emissions of most countries, it is clear that carbon offsets are being used to comply with law and regulations, as well as to offset historical and current corporate emissions (Bindman, 2021). Because the total possible amount of CDR is only 8.6 Gt/CO_2 per year on average from 2040-2060, and the average residual positive emissions across the land-use scenarios are 9.0 Gt/CO_2 per year, every available carbon offset must be directed toward negating the emissions of the world’s most difficult to decarbonize sector. Notably, these conclusions don’t necessarily apply to offset purchases in the present day, as the averages are for 2050-2100, and the 8.6 Gt/CO_2 per year from the Production Gap Report is from 2050. In theory, a company like Microsoft or other large corporations could be decarbonizing and purchasing offsets in tandem. However, the risk is a slowdown in the incentive to decarbonize. The pressure to change would be lessened and the pace of decarbonization would slow. This would lead to excess positive emissions after 2050 and the need for even more offsets to counterbalance them.

In the European ETS, over 60% of the offsets used in the compliance market went toward power generation (d'Aprile, Engel, Helmcke, et al., 2020). In the voluntary market, large institutions make offset purchases without behavioral changes. As put by Bloomberg, "JPMorgan executives continue to jet around the globe, Disney's cruise ships still burn oil, and BlackRock's office buildings gobble up electricity" despite there being alternative strategies for legitimate decarbonization, like solar/wind energy, electric vehicles, and more (Elgin, 2020). This leaves emissions from dirty industries like aviation and metal production un-negated and dampens any possibility that the world reaches net-zero and limits warming to 1.5℃. Moving forward, several reconsiderations around carbon offsets should be made.

Recommendations

1) Verifiable volunteer carbon offsets should be regulated in some way to ensure that they contribute to the global goal of net-zero by 2050, and are not wasted on institutional/corporate pledges. This should involve legislation or cooperation around companies that provide carbon offsets to clients and should involve a thorough vetting of what part of corporate emissions the offset will mitigate (e.g. transportation, electricity, aviation). If an institution cannot provide documentation showing the offset will mitigate emissions from a difficult to decarbonize source, then the litigation/agreements should deny that purchase. Furthermore, as reaching net zero already requires essentially complete decarbonization of the energy sector, counting the addition of renewables as a carbon offset (~40% of recent offsets) should be eliminated.
2) A version of this report with key findings should be sent to large institutional purchasers of carbon offsets to inform them of potential ethical and environmental issues

surrounding their offset purchases. Although major change may not arise from this, providing this new information could reframe how institutions consider purchasing offsets and encourage them to explore other avenues of decarbonization. Sending a version of this report would include a rubric to give institutions a starting point on alternatives to purchasing offsets and why their offset purchase hinders the global drive to net-zero. A copy of the rubric is available as Figure 12 in the appendix.

3) Further study is needed on adjusting IAM scenario inputs and model solving to account for some carbon offsets being used improperly, and therefore the full potential of offsets/CDR cannot be used to reach net-zero. IAMs have two main paths to generating an outcome. They can maximize welfare or minimize cost (Evans & Hausfather, 2018). Because difficult to decarbonize industries either do not have existing alternatives or they are too expensive at scale, the "least-cost" models will decarbonize every sector of the economy to reach warming targets before being left with the last remaining emissions. If those emissions cannot be decarbonized, then offsets help to mitigate their impact on global emissions. Relying on these models to make policy decisions when this paper has found that many offsets are being used to decarbonize sectors such as power generation risks the global community missing their goal of net-zero emissions.
4) Serious consideration should be given to outright ban or heavily regulate, on the scale of an international agreement, the use of carbon offsets to meet compliance targets within ETS systems. There are examples of ETS systems employing these strategies. In New Zealand, International offsets are banned. In China, the national ETS limits offset to 5% of a stationary installation's total output ("New Zealand Emissions Trading Scheme," 2021 and "China National ETS," 2021). However, because power stations can be large

emitters of CO_2, allowing even 5% of the total output to be covered by offsets may be too generous, considering the small margin of error. Similarly, in New Zealand, banning international offsets but permitting domestic ones may discourage decarbonization of the power sector and encourage using verified offsets within the country. A potential reconfiguring of ETS systems to outright ban offsets, and or setting aside a separate ETS system for difficult to decarbonize industries that allow offsets are both potential remedies.

Appendix

Table 1:

Summary Statistics												
Positive Residual Emissions	**All Scenarios CO2 Only**			**Land Use Subset CO2 Only**			**All Scenarios CO2 + N2O**			**Land Use Subset CO2 + N2O**		
	Mt CO2	Gt CO2	Ag. Gt/CO2 Per Year (2050-100)	Mt CO2	Gt CO2	Average Gt/CO2 Per Year (2050-2100)	Mt CO2	Gt CO2	Average Gt/CO2 Per Year (2050-2100)	Mt CO2	Gt CO2	Average Gt/CO2 Per Year (2050-2100)
Range (Max-Min)	1,913,000	1,913	-	1,913,000	1,913	-	1,907,004	1,907	-	1,906,604	1,907	-
Average	365,000	365	7.3	448,000	448	9.0	466,000	466	9.3	514,841	514	10.3
Standard Dev.	331,000	331	-	393,000	393	-	331,000	331	-	410,413	410	-
Coefficient of Variation	0.91	0.91		0.88	0.88		0.71	0.71		0.80	0.80	
Data Set	**Average Gt/CO2 Per Year**											
CO2 Only	7.3											
Land Use Subset (CO2 Only)	9.0											
CO2 and N2O	9.3											
Land Use Subset (CO2 Only)	10.3											

Table 2:

MP Data Tables

Table 3:

Linear Interpolation Excel Formulas:

5 Year Data	2.5*StartYear+5*SUM(Mid Years)+2.5*LastYear
10 Year Data	5*StartYear+10*SUM(Mid Years)+5*LastYear

Table 4:

Surrendered ERU or CER Units, ETS System, 2010-2012			
Unit Type	Sector (Code and Name)	Mt CO2	Gt CO2
ERU	20 Combustion of fuels	172.46	0.17
CER	20 Combustion of fuels	149.97	0.15
CER	20 Combustion of fuels	98.28	0.10
CER	20 Combustion of fuels	87.88	0.09
ERU	20 Combustion of fuels	36.29	0.04
ERU	24 Production of pig iron or steel	33.14	0.03
CER	24 Production of pig iron or steel	31.77	0.03
ERU	29 Production of cement clinker	28.50	0.03
CER	29 Production of cement clinker	25.69	0.03
ERU	21 Refining of mineral oil	21.89	0.02
ERU	24 Production of pig iron or steel	21.03	0.02
CER	24 Production of pig iron or steel	18.81	0.02
ERU	20 Combustion of fuels	14.23	0.01
CER	29 Production of cement clinker	12.29	0.01
CER	21 Refining of mineral oil	10.04	0.01
CER	24 Production of pig iron or steel	7.45	0.01
CER	30 Production of lime, or calcination of dolomite/magnesite	7.27	0.01
ERU	21 Refining of mineral oil	6.92	0.01
CER	29 Production of cement clinker	5.99	0.01
ERU	42 Production of bulk chemicals	5.92	0.01
CER	10 Aviation	5.63	0.01
ERU	29 Production of cement clinker	5.59	0.01
CER	21 Refining of mineral oil	5.45	0.01
ERU	10 Aviation	5.33	0.01
ERU	30 Production of lime, or calcination of dolomite/magnesite	4.85	0.00
CER	36 Production of paper or cardboard	4.62	0.00
CER	21 Refining of mineral oil	4.31	0.00
CER	31 Manufacture of glass	4.06	0.00

CER	36 Production of paper or cardboard	3.28	0.00
CER	30 Production of lime, or calcination of dolomite/magnesite	3.10	0.00
CER	42 Production of bulk chemicals	2.99	0.00
CER	31 Manufacture of glass	2.75	0.00
CER	30 Production of lime, or calcination of dolomite/magnesite	2.71	0.00
ERU	22 Production of coke	2.62	0.00
ERU	31 Manufacture of glass	2.40	0.00
CER	36 Production of paper or cardboard	2.25	0.00
ERU	36 Production of paper or cardboard	1.87	0.00
ERU	42 Production of bulk chemicals	1.79	0.00
CER	42 Production of bulk chemicals	1.70	0.00
ERU	21 Refining of mineral oil	1.69	0.00
ERU	32 Manufacture of ceramics	1.66	0.00
CER	31 Manufacture of glass	1.41	0.00
CER	42 Production of bulk chemicals	1.32	0.00
CER	22 Production of coke	1.13	0.00
ERU	22 Production of coke	1.11	0.00
ERU	29 Production of cement clinker	1.09	0.00
CER	32 Manufacture of ceramics	1.09	0.00
ERU	30 Production of lime, or calcination of dolomite/magnesite	1.09	0.00
CER	32 Manufacture of ceramics	1.05	0.00
CER	32 Manufacture of ceramics	1.02	0.00
CER	35 Production of pulp	1.02	0.00
CER	25 Production or processing of ferrous metals	0.87	0.00
CER	22 Production of coke	0.82	0.00
ERU	25 Production or processing of ferrous metals	0.79	0.00
ERU	36 Production of paper or cardboard	0.74	0.00
CER	35 Production of pulp	0.71	0.00
CER	35 Production of pulp	0.71	0.00
CER	25 Production or processing of ferrous metals	0.68	0.00
ERU	24 Production of pig iron or steel	0.67	0.00
ERU	32 Manufacture of ceramics	0.61	0.00
ERU	25 Production or processing of ferrous metals	0.59	0.00
ERU	23 Metal ore roasting or sintering	0.56	0.00
ERU	32 Manufacture of ceramics	0.52	0.00
CER	37 Production of carbon black	0.49	0.00

ERU	**33 Manufacture of mineral wool**	**0.45**	**0.00**
CER	**37 Production of carbon black**	**0.40**	**0.00**
ERU	**36 Production of paper or cardboard**	**0.40**	**0.00**
CER	**25 Production or processing of ferrous metals**	**0.39**	**0.00**
CER	**23 Metal ore roasting or sintering**	**0.36**	**0.00**
ERU	**35 Production of pulp**	**0.34**	**0.00**
CER	**22 Production of coke**	**0.32**	**0.00**
ERU	**41 Production of ammonia**	**0.32**	**0.00**
CER	**23 Metal ore roasting or sintering**	**0.31**	**0.00**
ERU	**37 Production of carbon black**	**0.27**	**0.00**
CER	**23 Metal ore roasting or sintering**	**0.27**	**0.00**
ERU	**30 Production of lime, or calcination of dolomite/magnesite**	**0.26**	**0.00**
CER	**33 Manufacture of mineral wool**	**0.26**	**0.00**
ERU	**44 Production of soda ash and sodium bicarbonate**	**0.25**	**0.00**
ERU	**41 Production of ammonia**	**0.22**	**0.00**
ERU	**41 Production of ammonia**	**0.19**	**0.00**
CER	**28 Production or processing of non-ferrous metals**	**0.19**	**0.00**
CER	**44 Production of soda ash and sodium bicarbonate**	**0.18**	**0.00**
ERU	**31 Manufacture of glass**	**0.17**	**0.00**
CER	**41 Production of ammonia**	**0.17**	**0.00**
ERU	**22 Production of coke**	**0.15**	**0.00**
ERU	**38 Production of nitric acid**	**0.15**	**0.00**
ERU	**43 Production of hydrogen and synthesis gas**	**0.14**	**0.00**
CER	**38 Production of nitric acid**	**0.14**	**0.00**
CER	**33 Manufacture of mineral wool**	**0.12**	**0.00**
ERU	**35 Production of pulp**	**0.12**	**0.00**
ERU	**42 Production of bulk chemicals**	**0.11**	**0.00**
CER	**99 Other activity opted-in under Art. 24**	**0.10**	**0.00**
ERU	**99 Other activity opted-in under Art. 24**	**0.09**	**0.00**
ERU	**25 Production or processing of ferrous metals**	**0.09**	**0.00**
CER	**33 Manufacture of mineral wool**	**0.09**	**0.00**
CER	**26 Production of primary aluminium**	**0.08**	**0.00**
CER	**43 Production of hydrogen and synthesis gas**	**0.08**	**0.00**
ERU	**26 Production of primary aluminium**	**0.08**	**0.00**
ERU	**28 Production or processing of non-ferrous metals**	**0.07**	**0.00**

ERU	34 Production or processing of gypsum or plasterboard	0.06	0.00
CER	38 Production of nitric acid	0.05	0.00
CER	43 Production of hydrogen and synthesis gas	0.05	0.00
CER	44 Production of soda ash and sodium bicarbonate	0.05	0.00
ERU	31 Manufacture of glass	0.04	0.00
CER	43 Production of hydrogen and synthesis gas	0.04	0.00
ERU	26 Production of primary aluminium	0.04	0.00
CER	41 Production of ammonia	0.03	0.00
ERU	35 Production of pulp	0.03	0.00
CER	28 Production or processing of non-ferrous metals	0.03	0.00
CER	37 Production of carbon black	0.02	0.00
ERU	27 Production of secondary aluminium	0.02	0.00
CER	28 Production or processing of non-ferrous metals	0.02	0.00
CER	41 Production of ammonia	0.02	0.00
CER	99 Other activity opted-in under Art. 24	0.02	0.00
CER	34 Production or processing of gypsum or plasterboard	0.01	0.00
ERU	28 Production or processing of non-ferrous metals	0.01	0.00
ERU	27 Production of secondary aluminium	0.01	0.00
CER	99 Other activity opted-in under Art. 24	0.01	0.00
CER	34 Production or processing of gypsum or plasterboard	0.01	0.00
CER	27 Production of secondary aluminium	0.01	0.00
CER	27 Production of secondary aluminium	0.01	0.00
CER	26 Production of primary aluminium	0.01	0.00
CER	27 Production of secondary aluminium	0.01	0.00
CER	34 Production or processing of gypsum or plasterboard	0.01	0.00
ERU	33 Manufacture of mineral wool	0.01	0.00
ERU	27 Production of secondary aluminium	0.01	0.00
ERU	26 Production of primary aluminium	0.00	0.00
ERU	99 Other activity opted-in under Art. 24	0.00	0.00
ERU	34 Production or processing of gypsum or plasterboard	0.00	0.00
CER	26 Production of primary aluminium	0.00	0.00
ERU	38 Production of nitric acid	0.00	0.00

ERU	**99 Other activity opted-in under Art. 24**	**0.00**	**0.00**
CER	**10 Aviation**	**0.00**	**0.00**
CER	**38 Production of nitric acid**	**0.00**	**0.00**
CER	**39 Production of adipic acid**	**0.00**	**0.00**
CER	**40 Production of glyoxal and glyoxylic acid**	**0.00**	**0.00**
CER	**45 Capture of greenhouse gases under Directive 2009/31/EC**	**0.00**	**0.00**
CER	**10 Aviation**	**0.00**	**0.00**
CER	**39 Production of adipic acid**	**0.00**	**0.00**
CER	**40 Production of glyoxal and glyoxylic acid**	**0.00**	**0.00**
CER	**44 Production of soda ash and sodium bicarbonate**	**0.00**	**0.00**
CER	**45 Capture of greenhouse gases under Directive 2009/31/EC**	**0.00**	**0.00**
CER	**39 Production of adipic acid**	**0.00**	**0.00**
CER	**40 Production of glyoxal and glyoxylic acid**	**0.00**	**0.00**
CER	**45 Capture of greenhouse gases under Directive 2009/31/EC**	**0.00**	**0.00**
ERU	**10 Aviation**	**0.00**	**0.00**
ERU	**23 Metal ore roasting or sintering**	**0.00**	**0.00**
ERU	**28 Production or processing of non-ferrous metals**	**0.00**	**0.00**
ERU	**33 Manufacture of mineral wool**	**0.00**	**0.00**
ERU	**34 Production or processing of gypsum or plasterboard**	**0.00**	**0.00**
ERU	**37 Production of carbon black**	**0.00**	**0.00**
ERU	**38 Production of nitric acid**	**0.00**	**0.00**
ERU	**39 Production of adipic acid**	**0.00**	**0.00**
ERU	**40 Production of glyoxal and glyoxylic acid**	**0.00**	**0.00**
ERU	**43 Production of hydrogen and synthesis gas**	**0.00**	**0.00**
ERU	**44 Production of soda ash and sodium bicarbonate**	**0.00**	**0.00**
ERU	**45 Capture of greenhouse gases under Directive 2009/31/EC**	**0.00**	**0.00**
ERU	**10 Aviation**	**0.00**	**0.00**
ERU	**23 Metal ore roasting or sintering**	**0.00**	**0.00**
ERU	**37 Production of carbon black**	**0.00**	**0.00**
ERU	**39 Production of adipic acid**	**0.00**	**0.00**
ERU	**40 Production of glyoxal and glyoxylic acid**	**0.00**	**0.00**
ERU	**43 Production of hydrogen and synthesis gas**	**0.00**	**0.00**
ERU	**44 Production of soda ash and sodium bicarbonate**	**0.00**	**0.00**

ERU	45 Capture of greenhouse gases under Directive 2009/31/EC	0.00	0.00
ERU	39 Production of adipic acid	0.00	0.00
ERU	40 Production of glyoxal and glyoxylic acid	0.00	0.00
ERU	45 Capture of greenhouse gases under Directive 2009/31/EC	0.00	0.00
TOTAL		894.48	0.89

Figures 1-11:

Figure 1: Cumulative CO_2 Emissions

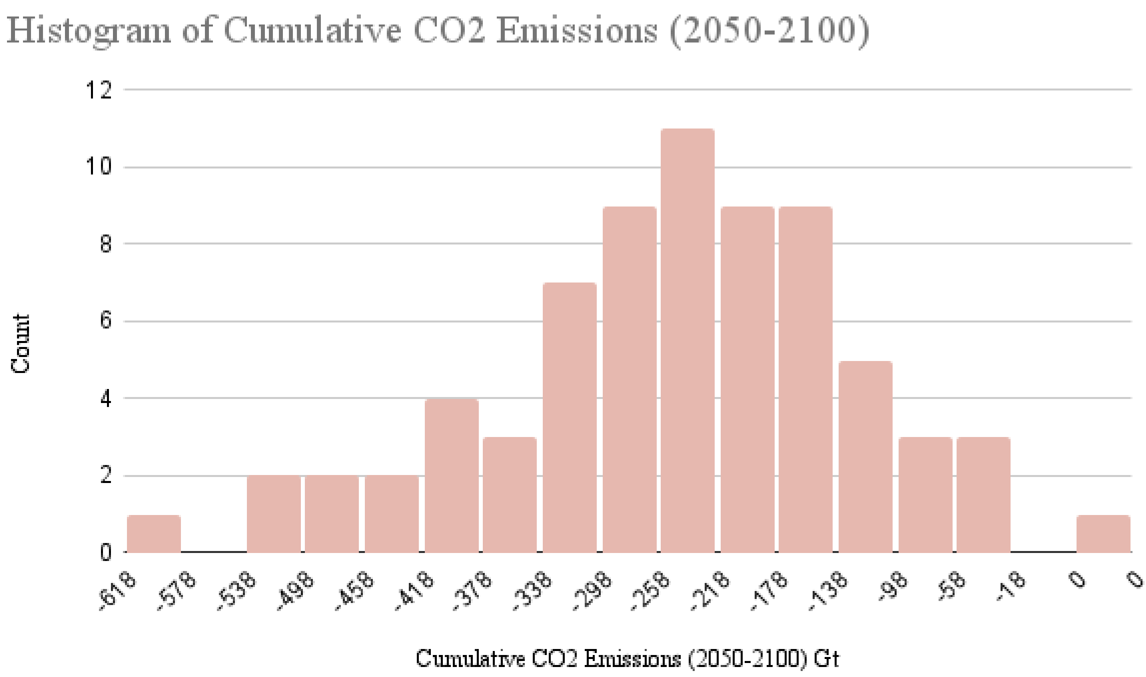


Figure 2: Cumulative CO_2 Emissions (Land Use Subset)

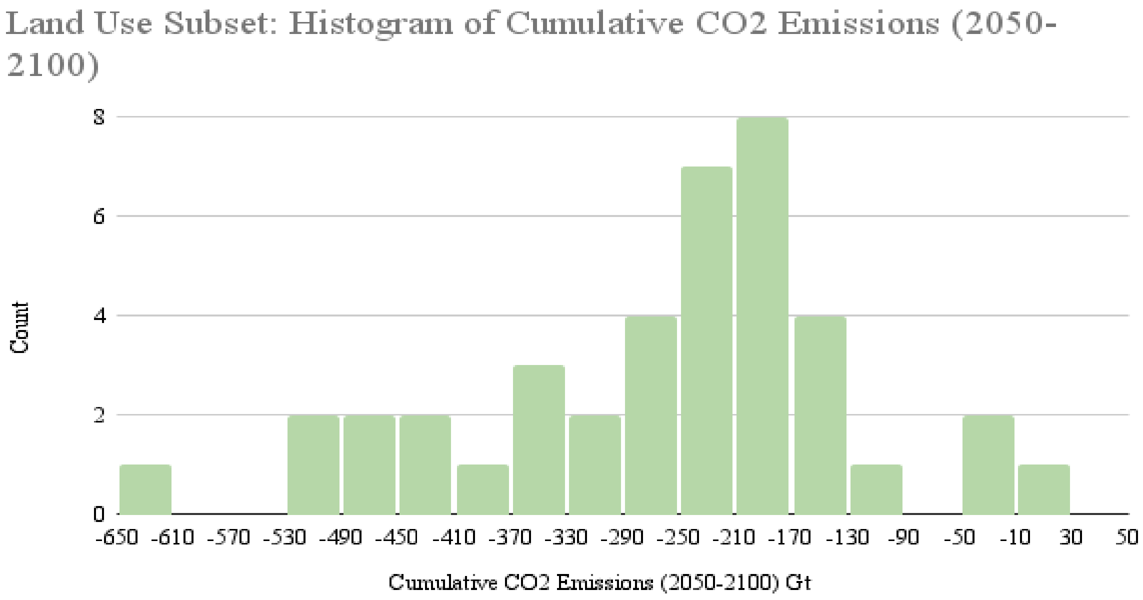


Figure 3: Cumulative Carbon Capture and Storage

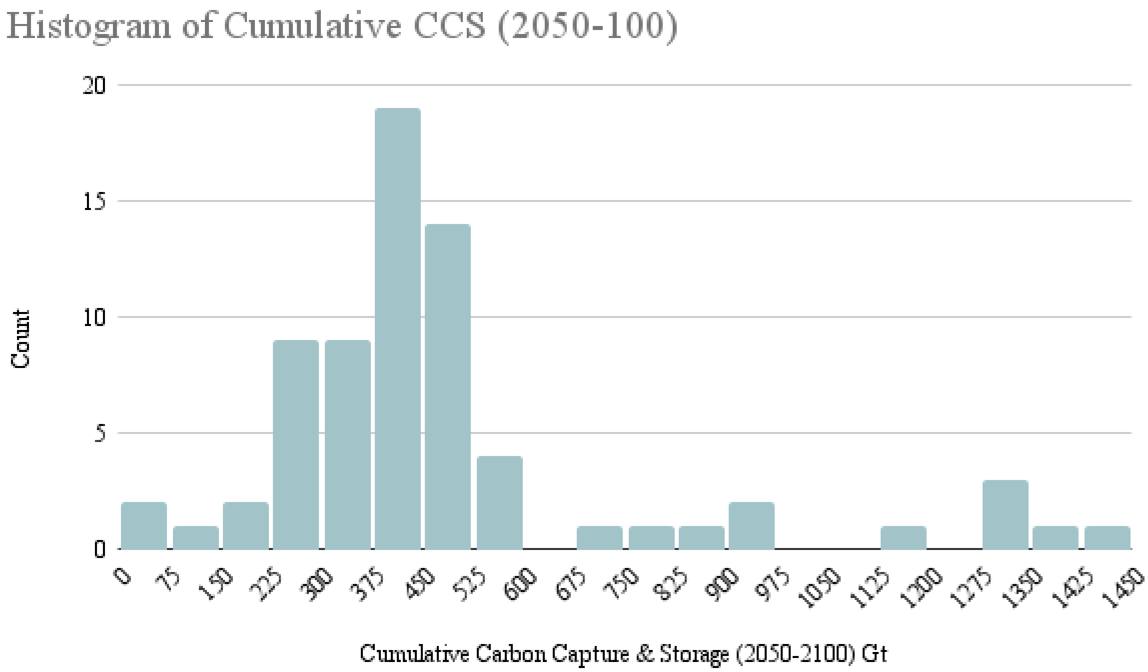


Figure 4: Cumulative Carbon Capture and Storage (Land Use Subset)

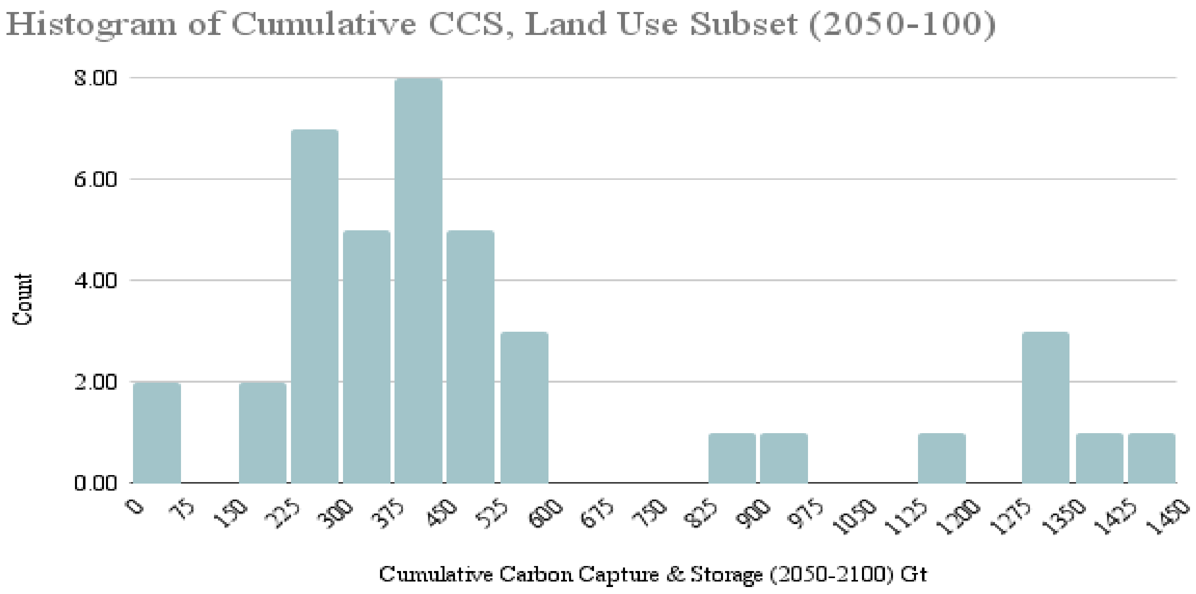


Figure 5: Cumulative Land Use CO_2 Sequestration

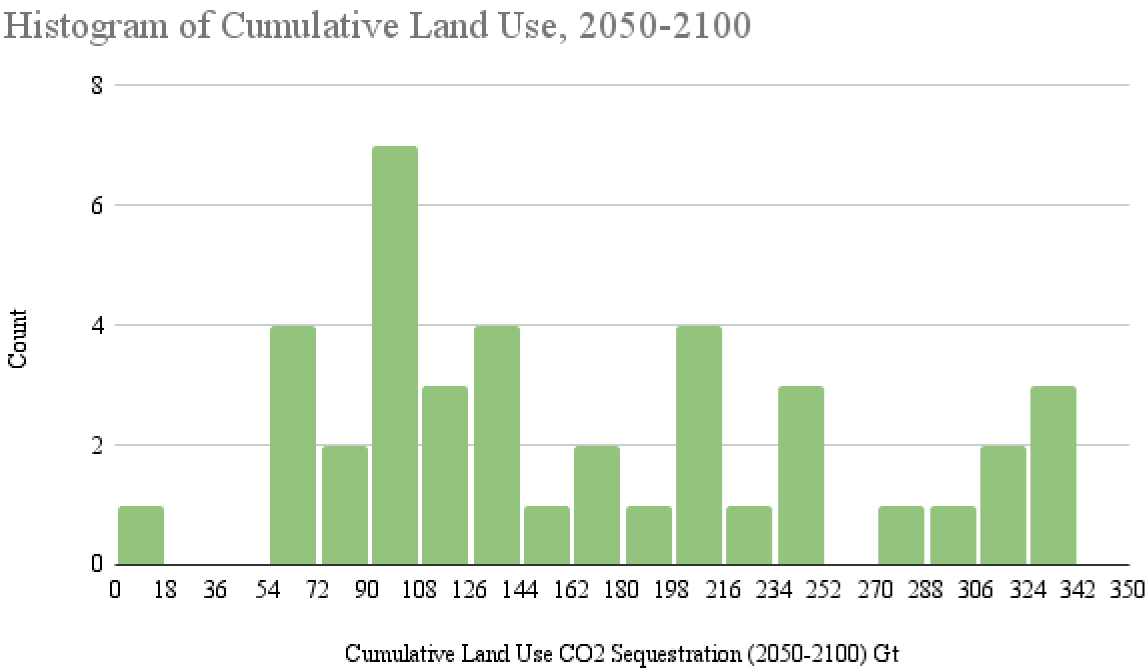


Figure 6: Residual Positive CO2 Emissions

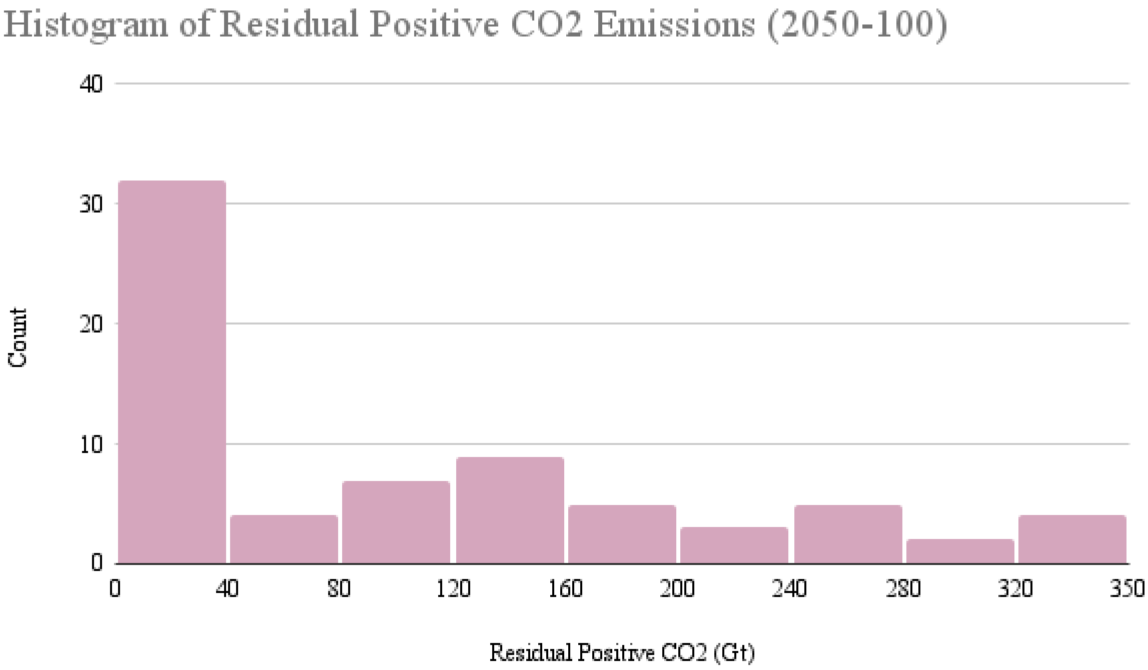


Figure 7: Residual Positive CO2 Emissions (Land Use Subset)

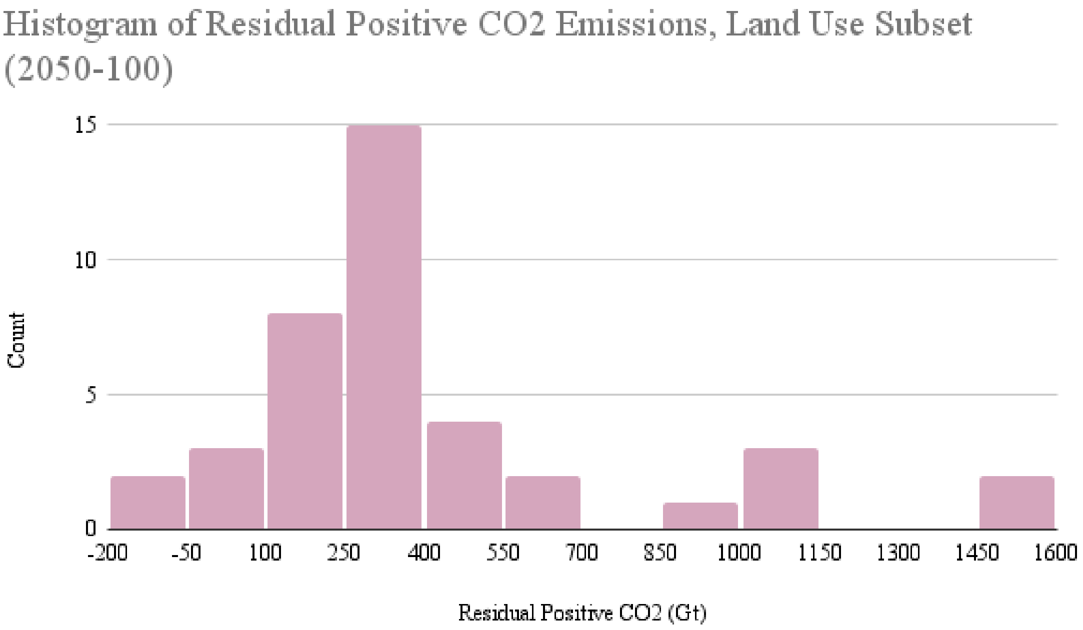


Figure 8: Cumulative N_2O Emissions (CO_2e)

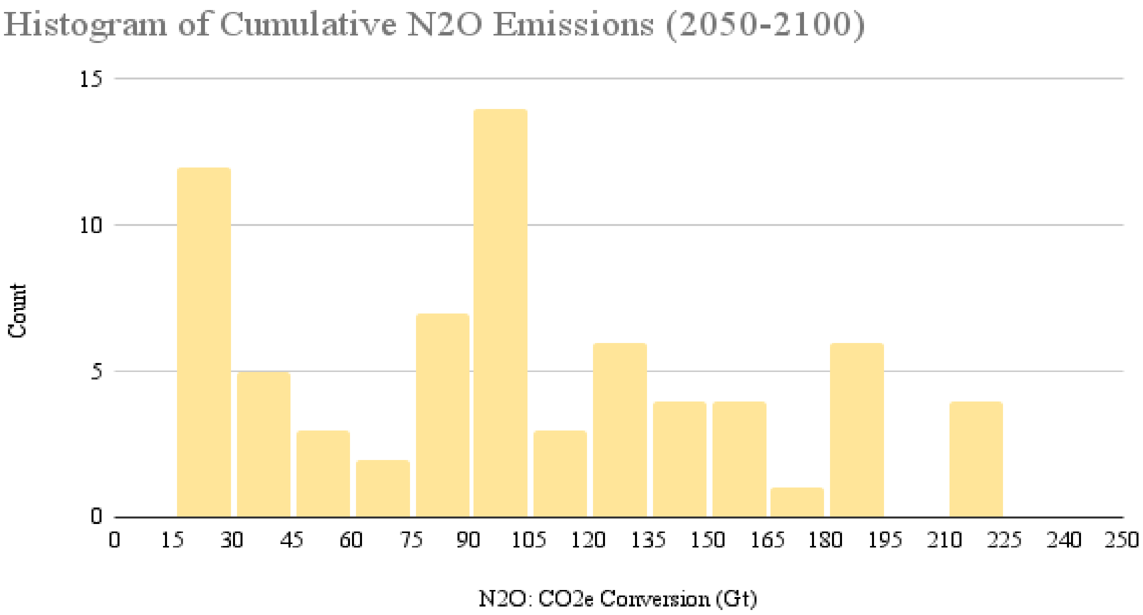


Figure 9: Cumulative N_2O Emissions (CO_2e) [Land Use Subset]

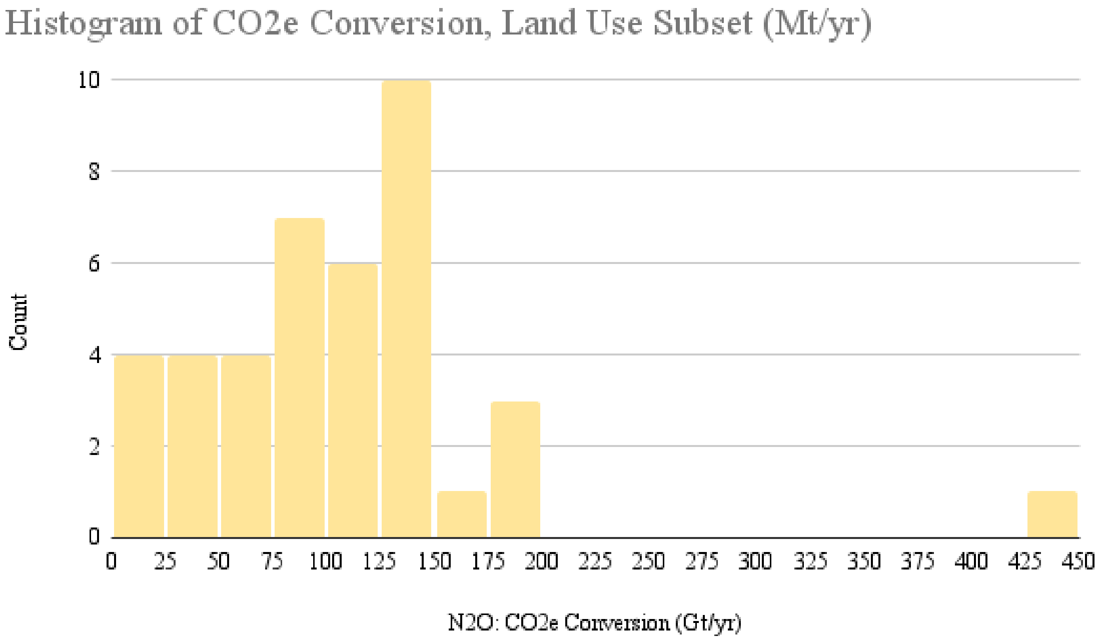


Figure 10: Positive Residual Emissions (CO_2+N_2O)

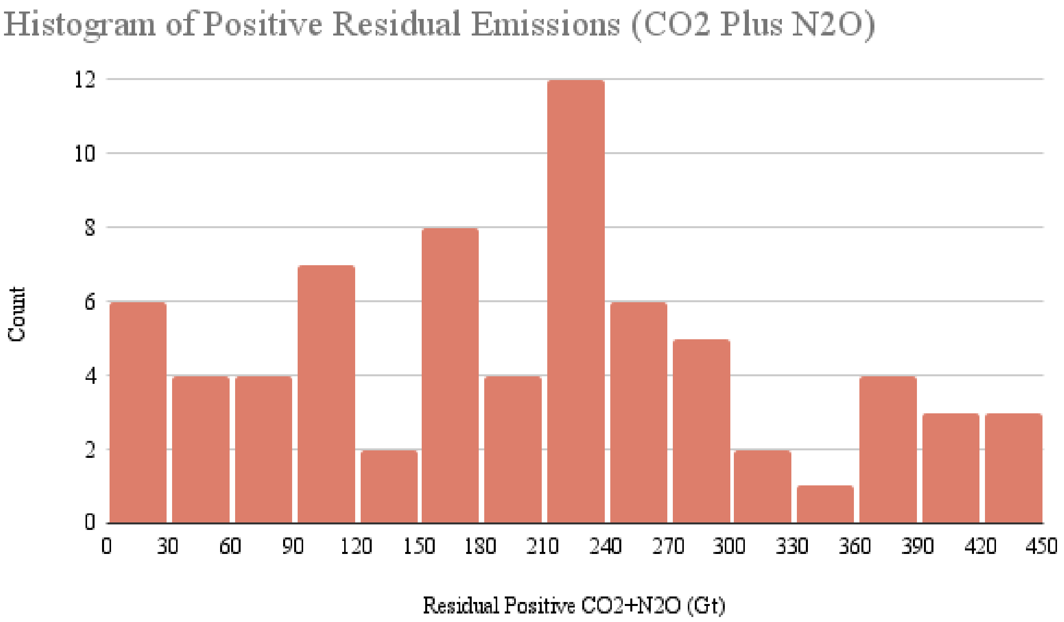
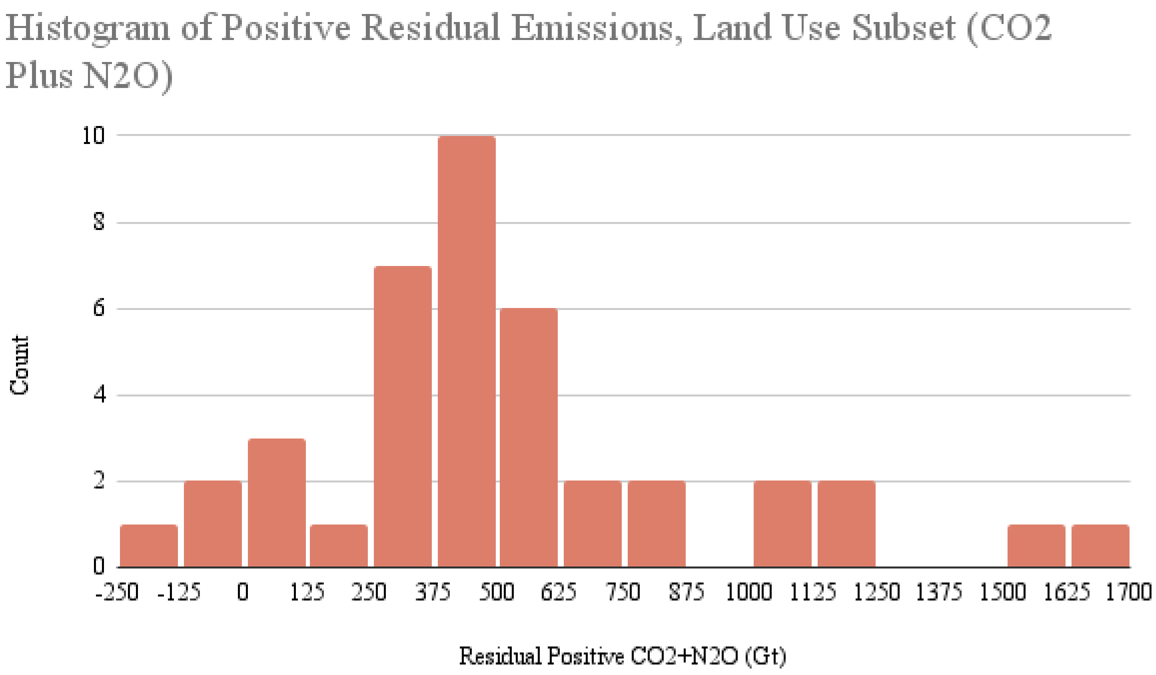


Figure 11: Positive Residual Emissions (CO_2+N_2O) [Land Use Subset]



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