



Reforestation and Carbon Sequestration: Opportunities for Regional Climate Mitigation

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Abstract

Planting trees is being seen more and more as one way that nature can be harnessed to lower CO₂ concentrations within the atmosphere by rehabilitating degraded areas. Nevertheless, regional differences in available land, land productivity, and land use play a role in the potential impact of such efforts on the environment. This study evaluated regional reforestation opportunities and associated carbon sequestration potential across the United States, with emphasis on county-level patterns, land-use contributions, and ecoregional variation. A quantitative cross-sectional design was applied using county-level and ecoregional reforestation opportunity data. The final analytical dataset included 3,109 county observations. Descriptive statistics, Pearson correlation analysis, ordinary least squares regression, land-use contribution analysis, state-level aggregation, county hotspot identification, and ecoregional comparison were conducted using Python. The reforestation opportunity area showed a strong positive association with carbon sequestration potential ($r = 0.848$), and regression analysis explained 71.8% of the variation in sequestration potential. Texas recorded the highest total state-level sequestration potential, while Oregon and California contained major county-level hotspots. Pasturelands contributed the largest share of total carbon sequestration potential, followed by shrub and grass systems. Ecoregional analysis identified Southeast U.S. conifer savannas, Appalachian Piedmont forests, and Piney Woods as leading ecological regions for reforestation-based mitigation. Reforestation will be able to make significant contributions towards regional climate mitigation, provided that its planning is based on factors such as land availability, ability to store carbon dioxide, suitability for land use, and ecological conditions.

Keywords: Reforestation, carbon sequestration, climate mitigation, land use, regional restoration

1. Introduction

Climate change is now one of the most important environmental issues that impacts ecological stability, economic systems and human health globally. The increase of GHGs in the atmosphere has led to enhanced global warming and regional and planetary scale changes in climatic processes (Mikhaylov et al., 2020). The industrialization and land-use changes, transport and energy production are anthropogenic activities that have caused the buildup of GHGs, significantly affecting long term climatic instability (Lamb et al., 2021). The main greenhouse gases that contribute to increases in temperature, ecosystem degradation and shifts in precipitation and atmospheric circulation patterns include carbon dioxide, methane, and nitrous oxide (Filonchik et al., 2024). As climate-related disturbances become more frequent and more intense, the need for sustainable mitigation strategies that can reduce atmospheric carbon concentrations whilst protecting the resilience of the ecosystems grows in importance. Forests are a key element in the regulation of the global carbon cycle by sequestering and capturing atmospheric carbon dioxide. Forest ecosystems are a large terrestrial source of carbon sink that sequesters carbon in vegetation biomass, soils and organic matter and thus reduces the net greenhouse gas concentration in the atmosphere (Hurteau, 2021). For this reason, reforestation has become a key NbS for climate change mitigation due to its ability to increase long-term carbon storage and to provide co-benefits in terms of ecology and socio-economics. The reforestation not only sequesters carbon but can also enhance biodiversity protection, restore degraded landscapes, stabilize soil, regulate the hydrological system and boost the resilience of the ecosystem under climate change (Di Sacco et al., 2021). This growing awareness of these benefits has brought more policy and scientific attention to national and international efforts for Forest Restoration.

Land-use change continues to be closely tied to changes in the carbon sequestration potential and ecosystem functioning. Habitat fragmentation and decreasing ecosystem carbon storage have been observed across the board due to agricultural expansion, urban development and resource extraction (Marques et al., 2019). The restoration of degraded and underused landscapes through reforestation is therefore seen as a crucial path to pursue both climate mitigation and ecological restoration goals. Geographically targeted restoration planning (Strassburg et al., 2020) has shown the critical need for

geographically targeted restoration assessments – spatial restoration assessments – that have demonstrated that some places have a disproportionately high potential for carbon accumulation and ecosystem recovery. Reforestation strategies, meanwhile, bring ecological and socioeconomic compromises regarding land availability, biodiversity results, food production systems, and sustainability aspects (Doelman et al., 2020). Proper mitigation planning should therefore include a balance of the potential for restoration benefits throughout the environment and region.

The importance of land management practices to increase terrestrial carbon storage has been increasingly highlighted in existing research on carbon sequestration. In an appropriate environment, better cropland and soil management can enhance the capacity for cropland carbon sequestration (Lessmann et al., 2022). There are also other climate mitigation options, such as ocean-based carbon removal strategies, which have been put forward as a way to remove carbon from the atmosphere, but there are still uncertainties about their long-term effectiveness and the ecological impact (Siegel et al., 2021). In terrestrial ecosystems, rangelands and pasturelands have become a significant focus due to their significant climate mitigation potential that can be achieved through restoration and sustainable management (Willard et al., 2025). The results suggest that traditionally agricultural or semi-natural landscapes can be key sites for reforestation-based carbon sequestration.

Spatial analysis of ecosystem services has also shown that spatial patterns of carbon storage are much affected by land-use and land-cover change at the regional level. Ecosystem services such as carbon sequestration are highly correlated with the spatial variability in land-use systems and environmental conditions in county-level studies (Chen et al., 2019). These discoveries highlight the need for regional evaluations that can recognize areas of potential restoration and carbon sequestration hotspots. While some of these global estimates have been developed and utilized to produce valuable estimates of the potential for restoration in other parts of the world, many of these large-scale assessments are still too coarse for regional-level climate mitigation planning. Specifically, there has been limited research that has assessed reforestation opportunity area, land-use contribution and ecological variability simultaneously at county and ecoregional scales in the U.S. Previous analyses tend to focus on global restoration targets and are relatively weak on the distribution of mitigation potential at the ecological, administrative and land-use level.

The current study seeks to fill this void by looking at the potential for reforestation in the United States and the carbon sequestration potential at the county and ecoregional levels. The study quantifies the statistical correlation between reforestation opportunity area and carbon sequestration potential, and pinpoints regional hotspot areas and land-use contributors to the mitigation potential. Sequestration potential is also evaluated in light of ecological variation among ecoregions to enhance understanding of the effects of ecological variation on the effectiveness of restoration. The study seeks to make a contribution to climate mitigation planning by identifying areas where reforestation is most likely to offer long-term carbon sequestration benefits through the use of integrated regional and ecological analysis.

2. Methodology

2.1 Research Design

This study used a quantitative, cross-sectional research design to assess the regional reforestation opportunities and related carbon sequestration potential in the United States. The analysis was based on the following: identifying spatial variability in reforestation capacity, analysing the relationship between the restoration opportunity area and carbon sequestration potential, and analysing the contribution of different land-use categories to climate mitigation outcomes. Two types of spatial analysis were carried out: at the county level and on the ecoregions, to explore administrative and ecological trends in reforestation-based carbon sequestration. This study used a secondary data analysis strategy and was geospatially derived, with environmental and land-use variables used. Patterns of sequestration potential were analyzed and high-priority mitigation regions identified using statistical modelling and comparative analyses.

2.2 Data Source

This study uses data from the U.S. reforestation opportunity assessment, which was created by Reforestation Hub (Reforestation Hub, 2025). This data set contains estimates of reforestation opportunity areas, carbon sequestration potential, and land-use characteristics for counties in the United States and for ecoregions. The assessment combines spatial environment data to provide an estimate of potential carbon gains for reforestation in various conditions. The variables included in this dataset were reforestation opportunity area, total carbon sequestration potential, sequestration rate, cropland carbon potential, pasture carbon potential, shrub and grassland carbon potential, urban open space carbon potential and associated regional identifiers. After data preparation and validation, a total of 3,109 observations at the county level were used in the analysis.

2.3 Data Preparation and Processing

The first step in processing the data was to import the county-level and ecoregional data sets and explore the data structure. The following variables were chosen for further analysis: reforestation opportunity variables and carbon sequestration variables. Data quality assessment involved checking the distribution of the variables, missing values, and duplicate data. There were no missing data or duplicate observations for the final data set for analysis. To standardize variable names and formats for consistency of analyses. Descriptive statistics were used to describe the distribution and variability of the major variables of the study. Then, grouped statistical operations were used to create county-level hotspot datasets, state-level summaries, and ecoregional aggregates. Contributions from land use to carbon sequestration potential were also developed as a dataset to quantify the proportion of carbon sequestration contributed by cropland, pasture, shrub/grass systems and urban open spaces.

2.4 Statistical Analysis

Descriptive statistical analysis was used to summarize the characteristics of central tendency and dispersion of the variables in the study. For the reforestation opportunity area, carbon sequestration potential, sequestration rate and carbon variables per land-use, mean, standard deviation, quartiles and maximums were calculated. Pearson correlation analysis was done to assess the relationship between reforestation opportunity area, sequestration potential and land-use variables in terms of strength and direction. Values of the correlation coefficient were interpreted to determine variables with a strong association with the carbon sequestration potential. Ordinary least squares linear regression analysis was used to analyze the relationship between reforestation opportunity area and total carbon sequestration potential as predictors. The proportion of the variation in sequestration potential that could be accounted for by the restoration opportunity area was estimated using the regression model. Comparative regional analyses have been performed at two levels – the state level and the ecoregional level. State-level aggregation was applied to identify the areas with the greatest cumulative carbon sequestration potential, and ecological analysis by ecoregion was conducted to assess the ecological variability of carbon sequestration potential. Hotspot analysis was also performed at the county level to determine the highest mitigation potential.

3. Results

3.1 Descriptive Characteristics of Reforestation and Carbon Sequestration Potential

The county-level data showed significant spatial variation of reforestation opportunity area and carbon sequestration potential across the United States. The mean reforestation opportunity area was 53,953.52 acres, but ranged anywhere from 0 to over 1.14 million acres, reflecting strong regional heterogeneity in the potential for reforestation. Similarly, the mean carbon sequestration potential was 100,340.58, with the highest potential being more than 2.27 million in high-capacity counties. Sequestration rate, too, varied greatly, with values from 0 to 3.26, indicating that there were significant differences in the efficiency of ecosystems across counties. The highest mean carbon sequestration potential in the land-use classes was found in pasture systems (47,191.47) and shrub and grass systems (27,881.04). Crops also had lower sequestration potential compared to urban open spaces, which had significant sequestration potential. The results show that reforestation-based climate mitigation opportunities are mainly in non-cropland landscapes.

Table 1. Descriptive statistics of reforestation opportunity and carbon sequestration variables

Variable	Mean	Standard deviation	Minimum	25th percentile	Median	75th percentile	Maximum
Reforestation opportunity area	53,953.52	69,795.92	0.00	6,143.30	37,603.42	75,972.67	1,140,945.26
Carbon sequestration potential	100,340.58	133,701.16	0.00	6,710.54	67,397.76	143,504.85	2,270,566.58
Sequestration rate	0.62	0.62	0.00	0.03	0.46	1.05	3.26
Cropland carbon potential	5,213.34	17,813.46	0.00	0.00	161.13	3,513.49	431,264.21
Pasture carbon potential	47,191.47	67,421.64	0.00	15.12	16,762.47	70,910.83	451,452.54
Shrub and grass carbon potential	27,881.04	92,361.44	0.00	151.56	3,091.26	21,920.83	1,766,151.15
Urban open space carbon potential	20,054.72	25,216.81	0.00	478.05	13,140.22	28,831.37	209,431.24

3.2 Relationship Between Reforestation Opportunity and Carbon Sequestration

There was a very good correlation between reforestation opportunity area and carbon sequestration potential. Pearson correlation analysis revealed a significant positive relationship between restoration opportunities and mitigation capacity ($r = 0.848$); counties with greater restoration opportunities tended to have greater mitigation capacity. The regression model also showed that the reforestation opportunity area accounted for around 71.8% of the variance in carbon sequestration potential ($R^2 = 0.718$). The correlation matrix showed that the sequestration potential in both shrub ($r = 0.763$) and grass ($r = 0.670$) had strong relationships with the overall sequestration potential, highlighting the relevance of the land-use systems for regional mitigation planning. Figure 1 shows the regression relationship, and there is a consistent increase in the potential carbon sequestration for a bigger reforestation opportunity area.

Table 2. Pearson correlation matrix among major reforestation and carbon sequestration variables

Variable	Reforestation opportunity area	Carbon sequestration potential	Sequestration rate	Cropland carbon potential	Pasture carbon potential	Shrub and grass carbon potential	Urban open space carbon potential
Reforestation opportunity area	1.000	0.848	0.437	0.090	0.524	0.708	0.435
Carbon sequestration potential	0.848	1.000	0.614	0.148	0.670	0.763	0.613
Sequestration rate	0.437	0.614	1.000	0.173	0.747	0.148	0.592
Cropland carbon potential	0.090	0.148	0.173	1.000	0.035	-0.032	0.100
Pasture carbon potential	0.524	0.670	0.747	0.035	1.000	0.081	0.556
Shrub and grass carbon potential	0.708	0.763	0.148	-0.032	0.081	1.000	0.188
Urban open space carbon potential	0.435	0.613	0.592	0.100	0.556	0.188	1.000

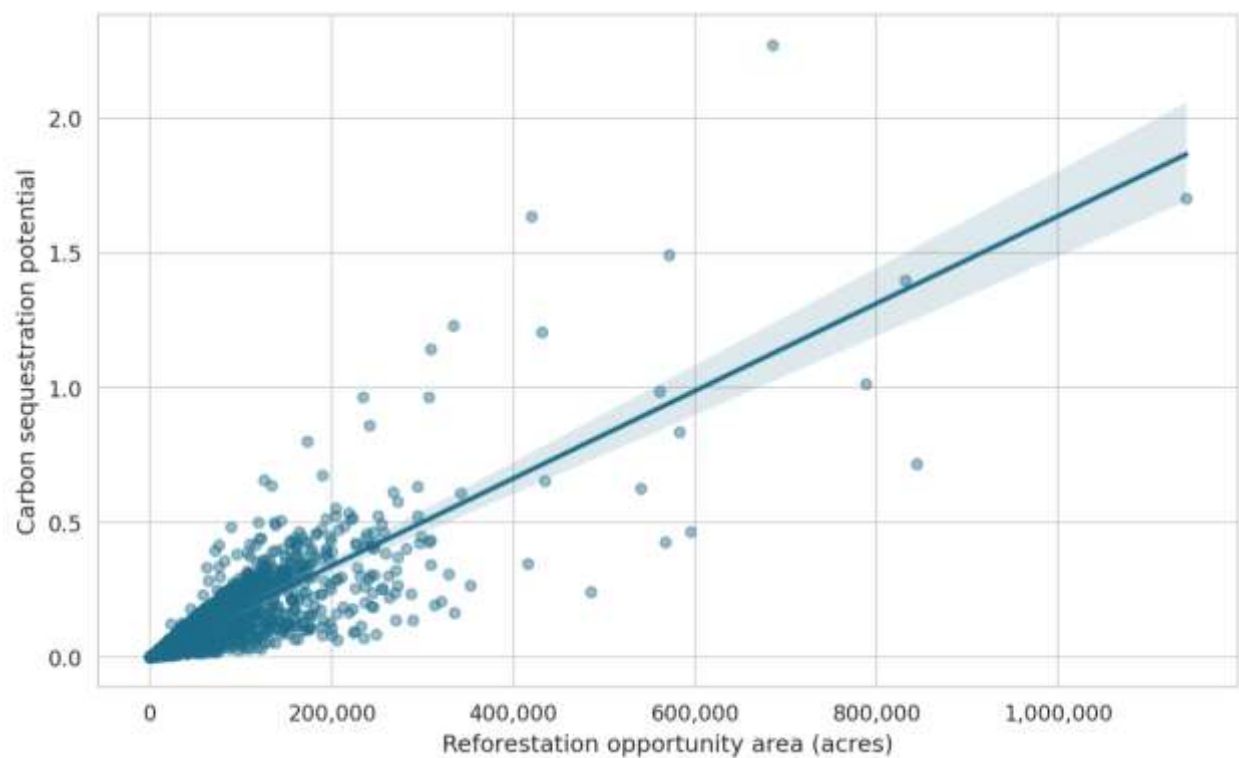


Figure 1. Reforestation Opportunity and Carbon Sequestration Potential

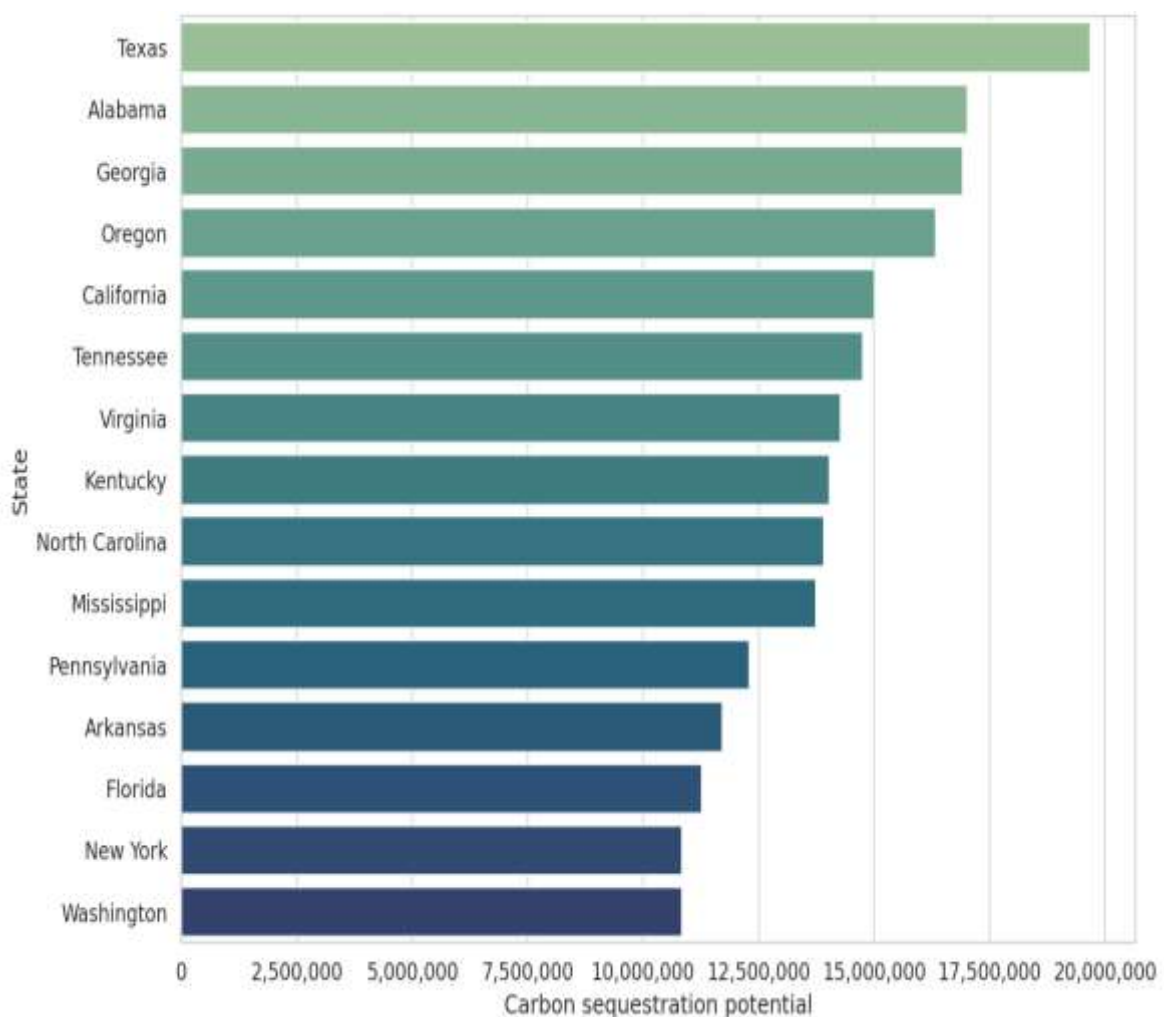
While some counties had very high sequestration values, the positive sequestration trend overall was consistent throughout the national data set, reflecting consistent mitigation benefits from reforestation.

3.3 Regional Patterns of Carbon Sequestration Potential

There was significant interstate variability in the United States. Texas had the largest total carbon sequestration potential (19.69 million), followed by Alabama, Georgia, Oregon, and California. Southeastern states tended to have high sequestration efficiency, and western states had larger reforestation opportunity areas due to the large share of forest landscape. Results from the state-level analysis further indicated that sequestration rates were relatively high in several Appalachian and southeastern states, implying that conditions were favorable for carbon accumulation on this longer time scale. As shown in Figure 2, reforestation-based mitigation potential is particularly high in the southern and western states.

Table 3. Top states by carbon sequestration potential

State	Total reforestation area	Total carbon sequestration potential	Mean sequestration rate
Texas	17,396,412.92	19,685,257.69	0.37
Alabama	6,972,109.03	17,025,347.05	1.30
Georgia	6,803,960.32	16,919,007.90	1.16
Oregon	7,558,602.39	16,336,377.23	0.95
California	8,599,715.23	15,019,241.32	0.40
Tennessee	6,886,462.69	14,759,590.13	1.37
Virginia	5,637,469.15	14,266,284.47	1.21
Kentucky	6,755,750.56	14,025,248.84	1.39
North Carolina	5,326,832.12	13,911,344.87	1.08
Mississippi	5,039,961.08	13,737,538.30	1.10
Pennsylvania	6,007,014.39	12,296,116.66	1.05
Arkansas	6,234,888.15	11,709,760.08	0.86
Florida	6,005,216.26	11,260,791.27	0.75
New York	5,502,000.65	10,841,107.45	0.87
Washington	4,408,039.33	10,837,345.33	0.67

**Figure 2. Top States by Carbon Sequestration Potential**

Texas had the highest carbon sequestration potential overall, and southeastern states had some of the highest potential. This allocation of space underscores the need for regionally prioritizing climate mitigation planning.

3.4 Land-Use Contributions to Carbon Sequestration

The carbon sequestration potential was significantly different among the land-use categories in the study area. The greatest individual sequestration opportunity was in pasture systems at around 47% of the total potential. Urban open spaces were close to 20%, and shrub and grass systems were close to 28%. By contrast, the share of cropland was very small. These results suggest that there is significantly larger potential for reforestation-based climate mitigation in a pasture-dominated landscape and a semi-natural landscape than in intensive agricultural landscapes. As can be seen in Figure 3, the greatest contribution to the total carbon sequestration potential is from the pasture landscapes.

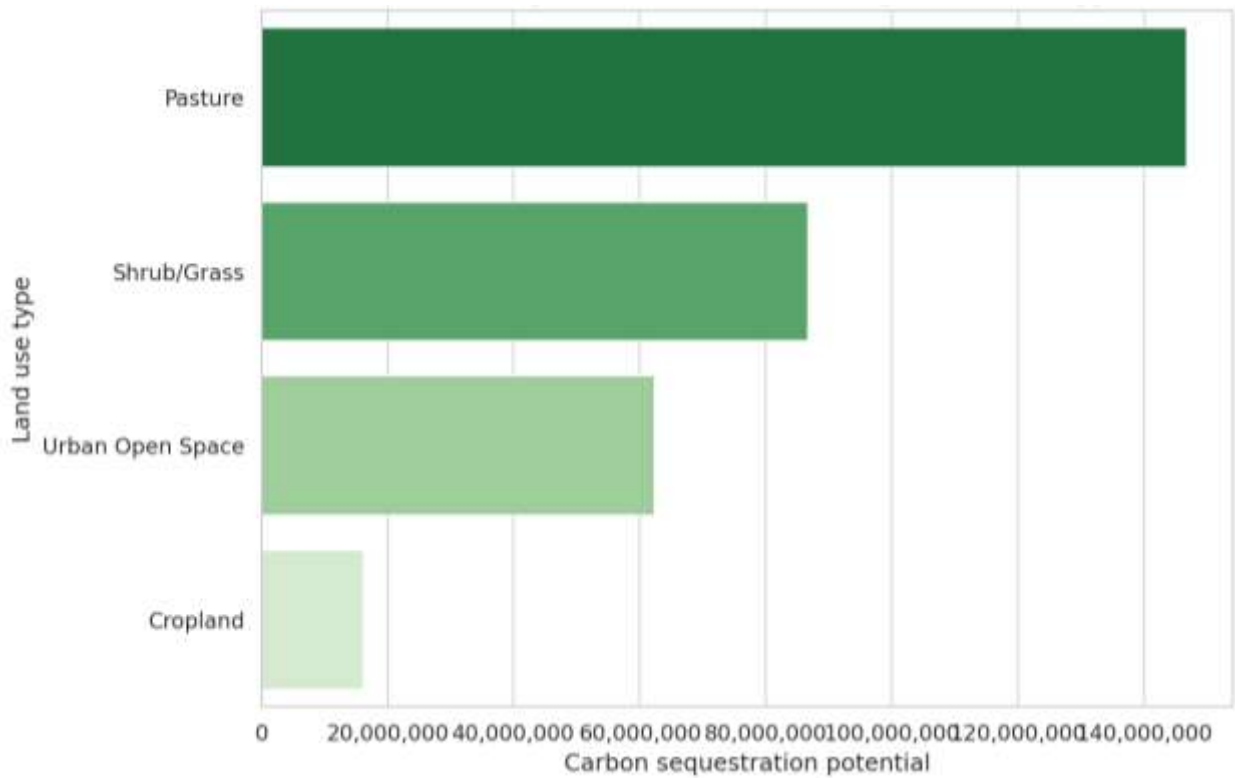


Figure 3. Carbon Sequestration Potential by Land Use Type

There was also a significant mitigation contribution from shrub and grass systems, while cropland had relatively low mitigation potential. The differences observed indicate that restoration projects on pasture and transitional vegetation systems could have the highest carbon benefit.

3.5 County-Level Hotspots of Carbon Sequestration

Geographic clustering of sequestration potential was found in western forest landscapes at the county level. The top carbon sequestration potential in the data set was found in Douglas County, OR, then in Siskiyou County, CA, and Trinity County, CA. Several Oregon counties were consistently in the top-performing areas in the nation. The hotspot distribution also showed that certain counties had very high sequestration efficiency in the presence of moderate reforestation opportunity areas, suggesting that there is significant ecological variability in forest systems. Figure 4 shows the density of high-capacity mitigation hotspots in Oregon and California.

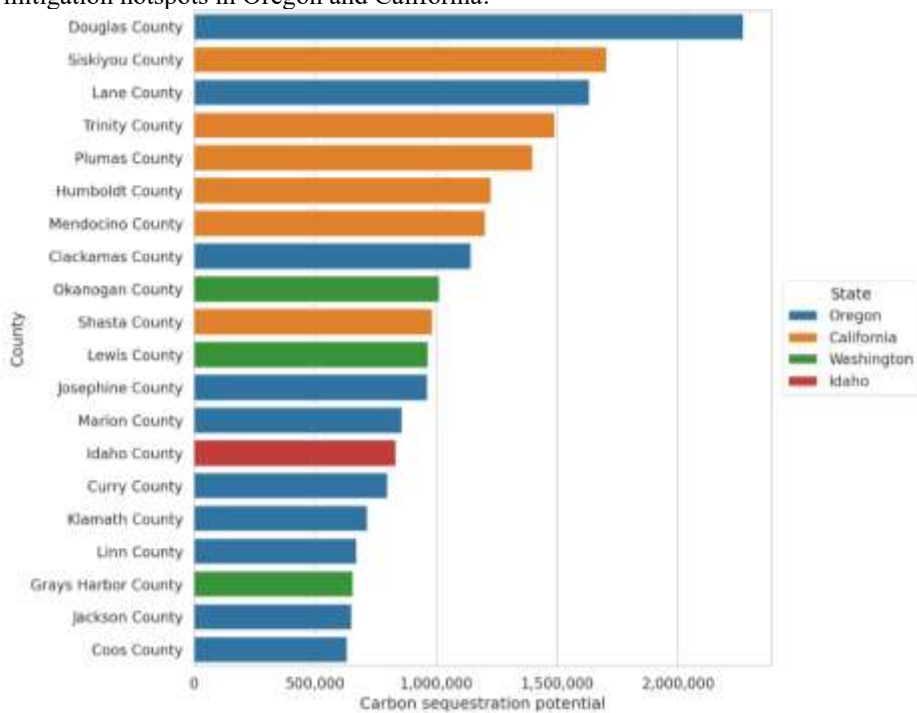


Figure 4. County Hotspots of Carbon Sequestration Potential

This interesting spatial pattern of top-performing counties in the Pacific coastal and montane forest systems strongly suggests that western forest systems are a significant component of the national carbon mitigation potential.

3.6 Spatial Dynamics of Reforestation-Based Mitigation Hotspots

The spatial relationship between the reforestation opportunity area and carbon sequestration potential among hotspot counties showed that there was a significant variation in mitigation efficiency. Some counties in California had high sequestration potential and large restoration opportunity areas; some counties in Oregon had high sequestration potential but smaller restoration opportunity areas. Across mitigation hotspots, the efficiency of carbon sequestration appears to be largely determined by the ecological productivity, forest composition and regional environmental conditions. The multidimensional relationship of reforestation opportunity area, carbon sequestration potential and regional hotspot distribution is shown in Figure 5.

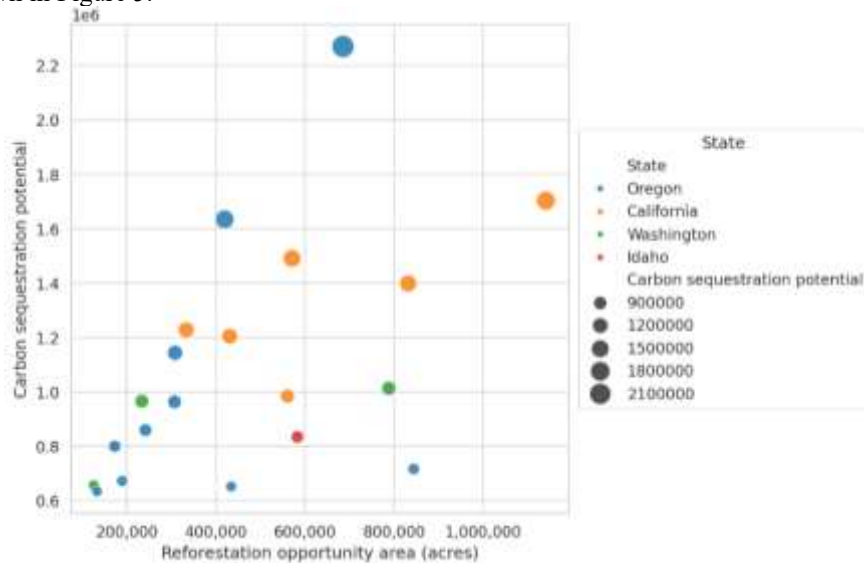


Figure 5. Hotspot Counties for Reforestation-Based Mitigation

Counties in the top right corner of the figure are those with above-average restoration opportunity and above-average mitigation potential, highlighting their strategic value to take climate policy action.

3.7 Ecoregional Variation in Carbon Sequestration Potential

There were also significant sequestration potential variations between ecological regions. The total C sequestration potential was highest for Southeast U.S. conifer savannas and was significantly greater than in all other ecoregions. Other forest types, such as Appalachian Piedmont forests, Piney Woods and Interior Plateau hardwood systems, also revealed consistently high mitigation capacity. There were several forest systems in the Pacific Northwest and the Appalachian region that indicated high sequestration rates for these types of forest, demonstrating that there are more efficient processes for carbon sequestration occurring in these ecological systems. As shown in Figure 6, southeastern conifer and Appalachian forest systems are the dominant ones in terms of national reforestation-based carbon sequestration potential.

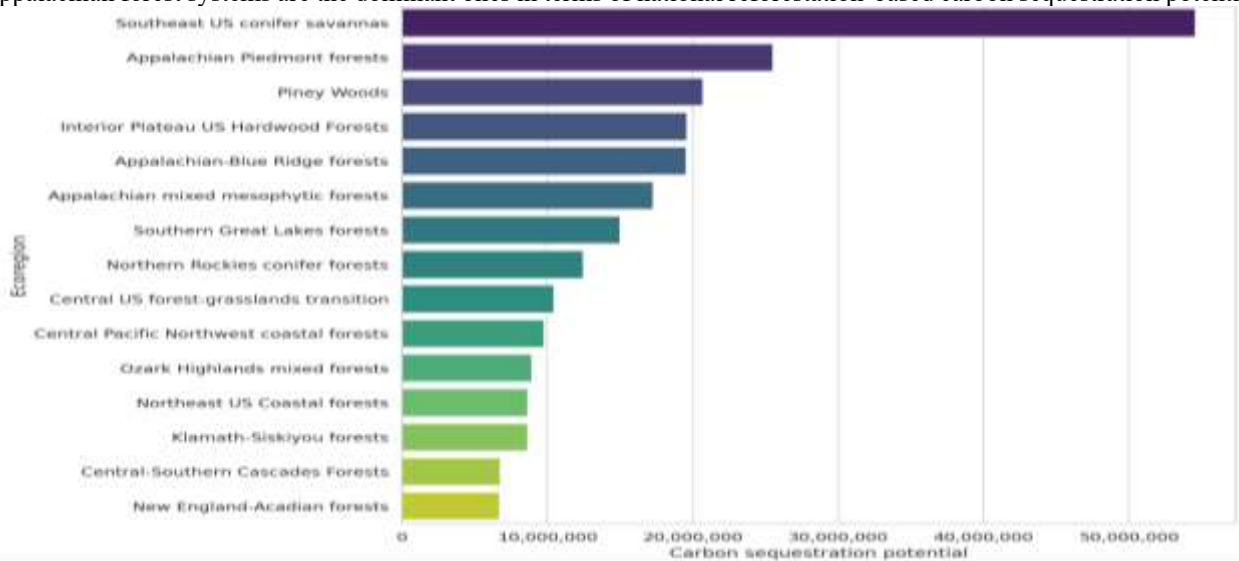


Figure 6. Top Ecoregions by Carbon Sequestration Potential

The ecological variation among ecoregions illustrates that differences in the climate mitigation capacity of regions are not only due to differences in available land but also to differences in the productivity of the land's ecosystem.

4. Discussion

Carbon sequestration capacity was highly correlated with potential for regional reforestation, meaning that potential for regional reforestation is also a key factor in determining mitigation potential across U.S. counties. The high explanatory

power and strong positive correlation of the regression model indicate that the carbon sequestration outcomes are generally better with larger reforestation areas. Meanwhile, differences in sequestration efficiency suggest that other factors such as ecological productivity, vegetation characteristics and environmental factors are also important for the performance of mitigation. There were different regional trends in the United States. Texas had the largest total sequestration potential owing to its large restoration opportunity area, and southeastern states (Kentucky, Tennessee, Georgia, Virginia and Alabama) had relatively high sequestration efficiency. The western forest ecosystems contribute more to national carbon mitigation than other forest ecosystems in the United States and were highlighted by the county-level hotspot rankings in Oregon and California. These results suggest that, in addition to land availability, ecological quality is also a factor in regional mitigation capacity. Land-use analysis also showed that pasturelands had the highest carbon sequestration potential, followed by the shrub and grass systems. Urban open spaces also provided notable mitigation opportunities, whereas cropland contributed comparatively less. This is suggestive that there can be more restoration benefits in semi-natural and transition landscapes than in intensive agricultural landscapes. This interpretation was confirmed by ecoregional analysis, which indicated that southern conifer systems and Appalachian Forest regions have strong sequestration capacity, as a result of their favorable ecology.

The findings align with research highlighting the significant role reforestation can play in mitigating climate change in ecologically realistic restoration scenarios (Fesenmyer et al., 2025). Restoration efforts can be spatially targeted and environmentally suitable, and deliver significant long-term mitigation benefits as shown in similar findings (Marvin et al., 2023). This good result for pasture and transitional landscapes is explained by evidence showing the potential for a large carbon sequestration benefit from reforestation and afforestation on underused lands (Ménard et al., 2023). The current work also agrees with the project-level assessments of carbon capture potential that have been shown to be dependent on the local eco-sociological context and landscape (Lefebvre et al., 2021). Similarly, the spatial variation among and between counties and ecoregions is related to questions from previous research about the sustainability of restoration benefits. Restoration of degraded landscapes does not always bring the expected benefits, as reforestation reversals and shifting land-use patterns can diminish or offset expected outcomes if restored landscapes are not well protected (Schwartz et al., 2020). Economic viability is also a crucial factor, especially when restoration efforts conflict with current land-use practices in the landscape (Morkovina et al., 2023). Another important consideration is that of climate sensitivity. Forest growth and the sequestration efficiency may change as a result of climate change, which has the potential to affect the long-term mitigation performance (Wang et al., 2022). The spatial prioritisation noted in this research is further supported by geospatial assessment, highlighting the need for environmental suitability and implementation feasibility for successful afforestation strategies (Burke et al., 2021).

The findings have important implications for regional climate mitigation planning. Investments in reforestation should be given the highest priority in areas with high restoration opportunity and high sequestration efficiency. States are strategically important mitigation areas, including Texas, Alabama, Georgia, Oregon and California, but the drivers for each sequestration potential vary from system to system. The prevalence of pasturelands and shrub-grass systems implies that restoration policies should emphasize the semi-natural and transitional landscapes more. A county-level hotspot approach can also help decision-makers, conservation groups, and land managers prioritize restoration funding to sites that can have the highest impact on climate change outcomes. Incorporating ecological variability in restoration planning may enhance the effectiveness and sustainability of reforestation-based mitigation.

Some caveats should be noted. This was based on secondary spatial data; the sequestration estimates are based on the assumptions made in the original modelling framework. The study was also of a cross-sectional design and hence did not consider the changes in sequestration potential over time. The socioeconomic variables, restoration costs and the land ownership conditions have not been included in the analysis. Climate projections, feasibility indicators for restoration and long-term ecological monitoring should be included in future research to enhance understanding of future changes in reforestation outcomes. Further research incorporating biodiversity, hydrological and socio-economic issues could also help to facilitate more detailed restoration planning.

5. Conclusion

Represented by a significant potential for climate mitigation, regional reforestation can be coupled with land restoration. Results show that the counties with larger reforestation opportunity areas also have higher carbon sequestration potential, but ecological conditions and land-use characteristics also influence the mitigation efficiency. Pasturelands and shrub-grass systems proved to be the most important land-use contributors, highlighting a need to focus on semi-natural and transitional landscapes during restoration planning. Regional results indicate that the opportunities for mitigation are not the same across the region. Texas and southeastern states and western forested counties are important contributors, and ecoregional patterns emphasize southeastern conifer systems, Appalachian forests and Pacific forest landscapes. The differences indicate that the reforestation policy would be more effective if it were spatially targeted than applied uniformly. Reforestation is a viable climate mitigation measure for regions, if done with an evidence-based approach that considers land availability, sequestration potential and ecological suitability. In planning the future, the benefits of carbon should be taken into account alongside feasibility for restoration, biodiversity value, land ownership and long-term climate resilience.

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