Mitigating Climate Change with the Conservation Reserve Program (CRP): The Role of Carbon Credits and CRP Redesign

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Abstract: This paper assesses the impact of adding carbon sequestration incentives to the U.S. Conservation Reserve Program (CRP). We use a comprehensive dataset from the USDA Economic Research Service to model how changes in the Environmental Benefits Index (EBI) for carbon sequestration affect CRP enrollments, budget allocations, and environmental outcomes. Our findings indicate that while prioritizing carbon storage enhances the program's benefits in terms of enduring environmental gains, it could reduce attention to other critical areas like wildlife habitat and soil erosion. This study highlights the trade-offs involved in adjusting conservation policies to incorporate climate change objectives.

Keywords: Conservation Reserve Program, carbon sequestration, caron credit payment, land conservation

JEL classification: Q15, Q24

1. Introduction

The resurgence of dialogue around the development of carbon credit markets in the United States coincides with the nation's renewed commitment to the Paris Agreement, a global initiative aimed at curtailing greenhouse gas emissions. Since rejoining the treaty in February 2021, the U.S. has embarked on ambitious objectives to abate greenhouse gas (GHG) emissions, drawing significant attention to the agricultural sector's role in climate mitigation efforts (Bonnie et al., 2020; Elder, 2021).

The Conservation Reserve Program (CRP), administered by the Farm Service Agency (FSA) of the USDA and covering 20.7 million acres as of May 2021, stands as a cornerstone in the U.S. agricultural conservation strategy. It aims to bolster the sector's capacity for climate change mitigation (FSA, 2021a,b). The FSA's initiative to offer up to a 10% increase in rental payments for CRP lands employing climate-smart practices marks a progressive step towards this goal (FSA, 2021a,c). Despite these efforts, the program's efficacy in GHG mitigation raises interesting questions: What is the scope of the CRP's carbon benefits, including GHG mitigation and carbon sequestration? How might farmers' CRP enrollment decisions be influenced by the program's incentives and carbon credit markets? Additionally, how can the CRP enrollment process be optimized to yield greater carbon benefits?

This study attempts to address these questions by performing economic analysis to inform and enhance the CRP's role in climate change mitigation. When evaluating the CRP, it is important to not only measure its environmental benefits but also farmers’ willingness to participate in it. As a voluntary conservation program, the CRP pays farmers annual rental payments in exchange for retiring land under conservation practices. With an average annual rental payment rate at $83/acre, the program's outlay is currently about $1.7 billion per year (FSA 2021d).

The development of carbon credits that offer payments for carbon benefits provides opportunities for farmers to earn additional revenues from their CRP land and for the CRP to reduce its program outlays (Bruner and Brokish 2021). For instance, if farmers are allowed to obtain and sell carbon credits from their CRP land by sequestering CO_2 or reducing GHG emissions, then CRP managers may have some freedom to reduce program rental payment rates while still keeping the enrollment acreage unchanged. Because carbon credit payments and CRP rental payments differ in risk and sources, farmers may have preference for one type of payment over the other. However, little is known about farmers' preferences regarding these two types of payments as well as any trade-offs between them. A potential caveat of the later versions of this research project will implement results a farmer survey to study farmers' willingness to enroll their land into the CRP under various payments schemes considering the potential interaction between carbon credit payments and CRP rental payments. Knowledge in this aspect will deepen our understanding about farmers' incentives to enroll their land into the CRP and will assist CRP program managers in harnessing the opportunities offered by emerging carbon credit markets to strengthen the CRP.

Since its establishment, the CRP has constantly evolved to meet the need from changing market conditions and environmental concerns over time (Hellerstein 2017; USDA, 2020). In its early stage (1985-1989), the CRP was designed to reduce soil erosion, with an enrollment mechanism that maximized total enrolled acreage (Reichelderfer and Boggess 1988; Ribaudo 1989). Starting in 1990, multiple environmental factors were introduced, and the concept of the Environmental Benefits Index (EBI) was used in order to balance environmental gains with program costs. During an enrollment period, each CRP offer is assigned an EBI value by the FSA and offers with EBI values larger than a national EBI cut-off value will be enrolled in the CRP.[1] As the crux of the CRP enrollment mechanism, the EBI has been changed a few times to adapt to technological and institutional constraints as well as environmental benefit targeting (Hamilton 2010, ch. 2; Hellerstein 2017; Jacobs 2010). Particularly, starting in 2003 (signup #26), carbon sequestration benefits of CRP land were included in the EBI to reflect the increasing interest in agricultural carbon sequestration during that time. However, since its inclusion, carbon sequestration benefits have only accounted for up to 10 EBI points among the maximum total 395 non-cost EBI points, about 2.5% (Jacobs 2010; FSA 2021a).

As Cattaneo et al. (2006, pp. 45) pointed out, the design of the EBI allowed program managers to adjust the maximum EBI points (the weights) assigned to a specific environmental benefit to reflect changed relative values of environmental benefits to society. Given the urgency of climate change mitigation, it is reasonable to consider increasing the maximum EBI points assigned to carbon sequestration benefits in the current design of EBI. However, because the CRP is a multi-objective program that balances various environmental benefits such as wildlife habitat cover, water quality, erosion reduction, and air quality (Cattaneo et al. 2006), an increase in the weight of one environmental benefit factor may affect other types of environmental benefits realized in program outcomes (Cattaneo et al. 2006). Moreover, due to the complexity and the national nature of the CRP, a change in enrollment mechanism can produce different environmental and economic implications across geographical regions.

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[1] There are two major types of enrollments in the CRP: General enrollment and continuous enrollment. The former allows farmers to enroll their land during specified sign-up periods to compete for acceptance whereas the latter is non-competitive and allows farmers to enroll their environmentally sensitive land in CRP at any time (Stubbs, 2014). As of May 2021, the CRP consisted of 11.3 million acres of general enrollment and 6.3 million acres of continuous enrollment (FSA, 2020). In this proposal we focus on general enrollment because it covers the majority of CRP land.

The way that CRP rental payments requested by farmers enter the EBI has also evolved since 1990. For the general signups over 1991-1995, the EBI design used rental payments to calculate benefit-cost ratios for program enrollment (Osborn 1993; Ribaudo et al. 2001; Jacobs et al. 2014). Commencing with the Federal Agriculture Improvement and Reform Act of 1996, the EBI underwent significant changes, and this benefit-cost ratio approach was discontinued. Instead, CRP rental payments were added to environmental components after a linear transformation, with larger rental payments implying lower EBI values. This additive approach remained to date and had been criticized for resulting in low cost-efficiency of the CRP (Miao et al. 2016). Moreover, how the potential carbon credit payments might be incorporated into the EBI will affect the environmental and geographical configurations of CRP enrollment. Therefore, a careful examination of the CRP enrollment mechanism (EBI) considering both the environmental benefit factors and cost factors is in order.

Since the enactment of the Food Security Act of 1985, the Conservation Reserve Program (CRP) has played a pivotal role in environmental conservation by withdrawing environmentally sensitive land from agricultural use and promoting the cultivation of plant species that enhance environmental health and quality. The program incentivizes farmers through annual rental payments—averaging $83 per acre as of 2021, amounting to approximately $1.7 billion in total disbursements annually (FSA, 2021d)—to adopt conservation practices. These practices not only reduce greenhouse gas (GHG) emissions associated with conventional farming (Robertson et al., 2000; Gelfand et al., 2011) but also enhance soil carbon sequestration (De et al., 2020).

In the quest to harmonize CRP objectives with the recently introduced carbon credit markets, it is vital to quantify the CRP's impact on carbon savings and soil organic carbon (SOC) sequestration. By providing financial incentives for carbon benefits, carbon credit markets offer a two main advantages, they enable farmers to gain additional income from their CRP lands and potentially allow the CRP to curtail its overall expenses (Bruner and Brokish 2021). If farmers can monetize carbon credits from CO2 sequestration or GHG emission reductions on their CRP land, the program could gain flexibility to adjust rental rates without altering the enrolled acreage.

Over the years, the CRP has evolved to align with shifting market dynamics and ecological imperatives (Hellerstein, 2017; USDA, 2020). In 1990, the program integrated a range of environmental factors into its framework, utilizing the Environmental Benefits Index (EBI) to equalize ecological gains with fiscal expenditures. The EBI scores, determined by the FSA during enrollment periods, dictate land eligibility based on a national cut-off value. The EBI, a cornerstone of the CRP's enrollment mechanism, has undergone several revisions to reflect technological progress and priority shifts in environmental benefit targeting (Hamilton 2012, ch. 2; Hellerstein, 2017; Jacobs, 2010). Notably, in 2003 (signup #26), the EBI began incorporating the carbon sequestration benefits of CRP land, marking a growing interest in agricultural carbon capture. Despite this, carbon sequestration has historically represented a meager fraction of the total EBI score, a mere 2.5% (Jacobs, 2010; FSA, 2021a), which suggests an opportunity to enhance this aspect in light of the urgency surrounding climate change mitigation. The intricate nature of the CRP means that alterations to its enrollment mechanism can have diverse environmental and economic consequences across regions. Initially, the EBI employed a benefit-cost ratio for enrollment decisions (Osborn, 1993; Ribaudo et al., 2001; Jacobs et al., 2014). However, following the Federal Agriculture Improvement and Reform Act of 1996, significant reforms to the EBI were enacted. The benefit-cost ratio methodology was supplanted by a linear transformation model that inversely correlates rental payments with EBI values, a system that has faced criticism for compromising the CRP's cost-efficiency (Miao et al., 2016).

The integration of carbon credit payments into the EBI is poised to reshape the environmental and geographical landscape of CRP enrollment. Thus, a meticulous evaluation of the EBI, considering both ecological and financial elements, is paramount. This paper delves into the ramifications of various proposed redesigns of the CRP enrollment mechanism, focusing on outcomes like carbon sequestration, environmental benefits, and acreage change. We explore the effects of amplifying the weight of carbon benefits within the EBI and analyze the combined influence of CRP rental and carbon credit payments on enrollment outcomes. Our objective is to deduce optimal strategies for leveraging the CRP to maximize GHG mitigation and assess its cost-effectiveness under diverse enrollment scenarios in the era of carbon credit markets.

2. Background of CRP enrollment mechanism

The enrollment of land into the Conservation Reserve Program (CRP) typically occurs through a competitive bidding process during specified general signup periods. Since the program's inception in 1985, its land enrollment efficiency and the subsequent environmental and economic repercussions have been a focal point of analysis. Reichelderfer and Boggess (1988), as well as Ribaudo (1989), critiqued the initial nine signup periods' design, which prioritized maximizing acreage over environmental benefits. Subsequent studies, such as those by Babcock et al. (1996, 1997), examined alternative enrollment designs under fiscal constraints, demonstrating that the efficiency loss of suboptimal designs was contingent on the correlation and variability between CRP offers' environmental benefits and the requested rental payments. Wu, Zilberman, and Babcock (2001) expanded on this by evaluating how different stakeholder groups favored the various designs.

Despite these insightful contributions, a gap remains regarding the cost-effectiveness of the current Environmental Benefits Index (EBI) design. Studies like Hellerstein et al. (2015) and Cramton et al. (2021) primarily focused on the implications of maximum CRP payment rates on cost-effectiveness using auction theory and economic experiments. Meanwhile, Cattaneo et al. (2006) deduced that minor adjustments to EBI weights minimally impact CRP outcomes. They did, however, acknowledge that significant alterations in these weights could reshape the program's outcomes if shifts in environmental improvement preferences occur.

However, the weight assigned to carbon benefits within the EBI was not the focus of these studies, casting uncertainty on their applicability to the primary focus of this research. The current EBI design's ability to accommodate more cost-effective structures remains untested, a question this study aims to explore. Miao et al. (2016) postulated that while the existing EBI design seeks to calibrate environmental gains with rental costs, it falls short on cost-effectiveness, instead appearing to optimize the net benefit per acre. The proposition for a cost-effective criterion involves a benefit-cost ratio aimed at maximizing environmental benefit per dollar. Utilizing data from Signup #26 and #41, their simulations indicated that an EBI design that integrates crop insurance premium subsidies could expand CRP acreage and environmental benefits without increasing governmental expenditure.

Our paper extends this inquiry by focusing on the potential interplay between the CRP and carbon credit markets. We investigate the influence of modifying EBI weights for carbon sequestration and analyze the enrollment outcomes across various EBI designs. Historically, the CRP has been directed by dual objectives: curtailing soil erosion and reducing agricultural surplus. This focus led to a rapid increase in enrollment strategy during its early signups. With legislative evolutions such as the Food, Agriculture, Conservation, and Trade Act of 1990, the

EBI was refined to a benefit-cost ratio design, enhancing enrollment efficiency by maximizing environmental gains for each dollar spent. The subsequent Federal Agriculture Improvement and Reform Act of 1996 saw the EBI evolve into its current form, where environmental benefits are linearly aggregated, and rental payments are adjusted post-linear transformation.

The current EBI encompasses a spectrum of environmental benefits, with erosion reduction, water quality, and wildlife benefits each assigned up to 100 points, while enduring benefits and air quality (which includes carbon sequestration) are valued at 50 and 45 points respectively. Carbon sequestration benefits are capped at 10 points within the air quality category. Under the prevailing CRP framework, an offer's EBI value is calculated using a linear equation that incorporates rental rates and environmental benefits. Offers surpassing a predetermined EBI threshold are accepted into the program. Increasing the weight given to carbon sequestration within the EBI could potentially prioritize land with greater carbon storage potential, underscoring the importance of CRP's role in climate change mitigation. This study will evaluate how such adjustments to the EBI could enhance the efficacy and environmental contributions of the CRP in the context of an evolving climate policy landscape.

The environmental benefits included in the current EBI are wildlife benefits, water quality benefits, erosion reduction, enduring benefits, and air quality benefits, where the former three types of benefits are assigned the same weights (maximum 100 points each), and the latter two are assigned a smaller weight (maximum 50 and 45 points, respectively). Carbon sequestration benefits are included in the air quality benefits and only account for up to 10 points[2]. Let EEBI denote the EBI points for environmental benefits of an offer and r denote the

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[2] (see FSA (2021c) for details about the EBI factors and their points used in the most recent signup period).

rent per acre requested in this offer. The EBI points of this offer under the current CRP specification can be written as:

$$EBI = EEBI + f(r) + c \tag{1}$$

where $f(r) = a \times (1 - r / b)$ is a linear function which transforms rental rate, r; parameters a and b are determined by the program administrator based on actual offer data in a signup period, indicating that they are unknown to farmers when CRP enrollment offers are made; and finally, c is the extra bonus points that are a relatively small numbers reflecting how much the requested rental rate is below the maximum payments that FSA is willing to offer. For each CRP offer, by using equation (1), the FSA assigns an EBI value to the offer based on the offer's environmental benefit factor and rental payment requested by the farmer. Then all offers are ranked according to their EBI values and offers with EBI values no less than the cut-off EBI value will be enrolled into the CRP. Intuitively, suppose the weight assigned to carbon sequestration benefits is increased in the EBI design. In that case, CRP offers with larger carbon sequestration capacity will be more likely to be enrolled in the CRP.

3. Empirical Approach

We aim to investigate to what extent an increase in the weight will enhance the capacity of the CRP to sequester carbon and the economic and environmental implications of such an increase under various EBI designs.

To investigate how to utilize the CRP to better mitigate GHG emissions we first define the EBI design in equation (1) as the benchmark EBI (denoted as EBI_0. That is, we have:

$$EBI_0 = EEBI + f(r) + c. \tag{1}$$

where $EEBI^{'}$ denotes the new EEBI after the weight of carbon benefits is modified and p denote carbon credit payment rate ($/acre/year). Then, deviating from the benchmark EBI design, we consider the following four alternative of EBI designs:

$$EBI_1 = EEBI^{'} + f(r) + c, \tag{2}$$

$$EBI_2 = EEBI^{'} + f(r-p) + c, \tag{3}$$

$$EBI_3 = (EEBI^{'} + c) / r, \tag{4}$$

$$EBI_4 = (EEBI^{'} + c) / (r-p), \tag{5}$$

Note that EBI_1 in equation (2) is the same as the benchmark EBI_0 except that the weight for carbon benefits is increased to a new level. Both EBI_0 and EBI_1 ignore the potential carbon credit payments in the EBI design (i.e., carbon credit payment rate, *p*, is missing in equations (1) and (2)). Different from EBI_1, EBI_2 in equation (3) considers the carbon credit payments that a CRP land tract may receive and deducts them from CRP rental payments. In other words, under EBI_2, CRP rental payment rate is max [0,r-p]. Unlike EBI_1 and EBI_2 that combine the CRP rent with environmental benefits after a linear transformation of the rent, EBI_3 and EBI_4 are simply obtaining benefit-to-cost ratios. The difference between EBI_3 and EBI_4 is that under EBI_3 the carbon credit payments are ignored whereas under EBI_4 the CRP rental payment rate is adjusted based on the amount of carbon credit payments.

Miao et al. (2016) shows that EBI_1 and EBI_2 are consistent with maximizing environmental benefits with a linear adjustment of program costs subject to an acreage constraint, whereas EBI_3 and EBI_4 are consistent with maximizing environmental benefits subject to a budget constraint.

The numerical simulation under will be based on equations (1) to (5) and CRP contract-level data in a specific general signup (e.g., signup #54 occurred in 2021, under which farmers made 56,788 offers). The dataset includes each CRP offer's detailed EBI points under each environmental benefit factor and EBI points associated with costs, as well as the rental rate requested by farmers. It also the acceptance status which indicates whether or not the FSA accepted an offer for a particular land parcel.

We use EBI_1 in equation (2) as an example to describe the procedure of obtaining enrollment outcomes under a new EBI design. First, based on the contract-level data, we calculate EEBI' for each offer under the new weight assigned to the carbon benefit factor. Then we insert EEBI' into equation (2) and obtain EBI_1 under this specific new weight for carbon benefits for each CRP offer. We then rank all offers in this signup according to their values of EBI_1. Offers with larger values will be enrolled into the CRP until the total enrolled acreage equals the enrolled acreage under that signup. We then calculate the environmental benefits and total program payments associated with the accepted offers under EBI_1 and compare them with enrollment outcomes under EBI_0 to quantify the impact of changes in EBI.

Similar procedures can be used to study the impact of adopting EBI_2, EBI_3, or EBI_4 on CRP enrollment outcomes. The carbon credit payment rate, p, will be calculated based on a carbon price of \$15/Mg and on the carbon benefits for each CRP offer based on the simulation results. To , each offer's potential carbon payment is calculated based on the carbon sequestration score (N5d) of the land, adjusted by a set base payment rate (\$15/Mg), and then scaled down by a factor of 2. The reason for scaling by 2 is due to the fact that 2 is the minimum N5d value that is larger than 0. This means that no score for carbon sequestration (N5d) will be less than 2, other than a score of 0 which indicates no carbon sequestration potential. Therefore, dividing by 2 scales the payment to a reasonable range, and ensures that for every unit increase in the N5d score, the payment increases by half the base rate. This is important because it prevents the payment from escalating too quickly for small increases in N5d and keeps the additional carbon payments proportional to the sequestration potential of the land. So, this scaling method serves a way to normalize the payment across various offers, ensuring that it remains proportionate to the N5d score while not allowing the payment to exceed a certain limit or to maintain it within a reasonable range relative to other CRP payments. We consider different weights for carbon benefits N5d, starting from 10 (the status quo) up to 100.

The scenarios that we analyze in the main text of the paper are described as follows:

Baseline scenario,(EBI_0), represents the current state of the EBI without considering potential carbon credit payments.

Scenario 1, (EBI_1) same as EBI_0 in structure but increases the emphasis on carbon sequestration. We inflate N5d (carbon sequestration), by 10 times to bring its range from "3 to 10" to "30 to 100." This adjustment is made because other environmental factors (like N1, N2, N3) are scaled at 100.

Scenario 2, (EBI_2) the presence of f(r−p) implies that the carbon credit payment is seen as a cost-saving factor for the CRP. This could incentivize landowners to engage in carbon sequestration practices by effectively lowering their rental payment obligations in the eyes of the CRP and potentially improving their EBI score.

Scenario 3, (EBI_3) is a benefit-cost ratio, no carbon credit payments, or adjustments to carbon sequestration points. It divides the environmental benefits by the cost of rental payments to prioritize offers that provide the highest environmental benefits for the lowest cost.

Scenario 4, (EBI_4) Here, the EBI considers a benefit-to-cost design and deducting the carbon payment from the rent. The carbon payment deduction from the rent effectively lowers the rental cost from the perspective of the program, while significantly increasing the weighting of the carbon sequestration benefit in the overall EBI score.

4. CRP Enrollment Data

Our analysis hinges on a comprehensive dataset obtained from the USDA Economic Research Service (USDA/ERS) that detail county-level enrollment statistics for the Conservation Reserve Program (CRP) for signup 54 which took place in 2021. A breakdown of variable statistics and interpretation of factors is presented in Table 1. The contract-level data affords us a unique look into the particulars of CRP participation, including the acreage committed, proposed rental payment bids, actual acceptance into the program, and the Environmental Benefits Index (EBI) scores correlated with each environmental goal. In the landscape of signup 54, we have at our disposal 56,788 individual records at the county level. An examination of these records discloses an average enrollment of approximately 67.6 acres per county. Landowners entered bids with an average CRP rental payment of $94.81 per acre. The EBI, which indicates a parcel of land's environmental benefit potential, held an average score of 273 points across submissions.

We analyze the dataset further by looking at the data in terms of overall participation vs the actual accepted offers. Table 2 reveals that in terms of total offers made vs actual accepted offers there were 56,788 offers made and 51,610 accepted, the acceptance rate under signup 54 is relatively high close to 91%. This suggests that a large proportion of the offers met the necessary EBI threshold, implying that most lands offered for enrollment aligned well with the CRP's environmental goals. In terms of acreage, total acres offered were 3,839,488, and 3,418,597 of these acres were accepted into the program.

The average CRP rental payment bid was $94.8 per acre, while the average payment for accepted offers was slightly higher at $95.2 per acre. This implies that higher rental payments are associated with offers that have higher environmental benefits and were thus accepted into the program. In terms of EBI scores there was difference of around 8.13 points in the average EBI score between parcels offered (273.89) and accepted (282.02) parcels of land while the average EEBI shows a smaller difference between offered (193.23) and accepted (201.33) bids, once again indicating CRP's preference for parcels with higher environmental benefits.

The data provides a solid foundation for analyzing the effectiveness of the CRP and the potential for integrating carbon credit markets. With a high acceptance rate and the average EBI score for accepted offers being higher than that for all offers, it is clear that the CRP is selective towards offers that promise a higher return in terms of environmental benefits. With the addition of carbon credit payments and the refinement of carbon sequestration as a factor in the EBI calculation there may be potential to further refine the program's impact on climate change mitigation.

5. Results

CRP outcomes under scenario simulations

Table 3 and 4 explain and illustrates the differential outcomes of the Conservation Reserve Program (CRP) under various simulation scenarios, each imposing different constraints, and adjustments to the program's enrollment criteria, specifically within the context of acreage and budget constraints. In Table 4, 50% acreage constraint represents enrolled CRP acreage in the county with a 50% acreage constraint imposed (under Status quo (baseline), Scenario 1, and Scenario 2). The baseline represents the current status quo of the CRP without any modifications. The program under the acreage constraint has 1.9 million acres enrolled, with a total payment for these acres amounting to $112.7 million and total EEBI acreage weighted points of 403 million. Under scenario 1 there was a modest increase in total payment (2.27%) suggesting a slight improvement in the program's cost without a notable change in acreage. There’s a negligible decrease in EEBI points (-0.046%), which implies a very minimal trade-off between cost and environmental benefits. Scenario 2 shows a further increase in total payment (3.01%) compared to the baseline. Similar to Scenario 1, there’s a minimal decrease in EEBI points (-0.00228%), an even smaller trade-off compared to Scenario 1.

For the 50% Budget Constraint, scenario 3 acts as a reference point for budget-constrained scenarios (scenario 3 represents the alternative status quo or alternative baseline), where 3.1 million acres are enrolled, and the total payment for these acres is $102.5 million, with EEBI points at 498 million. Scenario 3 shows a decrease in acres enrolled (-0.593%) compared to the alternative baseline, indicating that under this scenario slightly fewer acres are enrolled for the same budget, potentially reflecting a tighter selection based on the adjusted criteria. There is also a minor decrease in EEBI points (-0.00117%), suggesting a marginal reduction in environmental benefits. Scenario 4 shows a larger decrease in total acres enrolled (-0.858%) compared to alternative baseline, again showing that the criteria applied under this scenario are more selective. However, there's a slight increase in EEBI points (0.00467%), suggesting an improvement in environmental benefit scores per acre enrolled under this budget constraint.

Overall, the numeric differences in the table may seem marginal, but spatially, these impacts can vary significantly. Different areas have varying environmental and soil characteristics which can affect the efficiency of carbon sequestration and the overall environmental benefits. A small increase in EEBI points in a region with high carbon sequestration potential could lead to substantial environmental improvements. The changes in enrolled acres might be concentrated in specific regions where the land is more conducive to achieving the CRP's objectives. Therefore, the environmental impact could be significant in these areas even if the overall acreage change is small. Additionally, even slight shifts in payment rates can have meaningful economic consequences for the regions that depend heavily on agriculture. This could mean that the economic ripple effects in rural communities may be more pronounced than the percentage changes suggest. Moreover, benefits like erosion control, water quality improvement, or wildlife habitat enhancement could be more significant in certain areas, meaning that even small changes in the CRP could lead to greater benefits in those particular environmental aspects.

While the table estimates provide a useful overview, a spatial analysis is essential to fully grasp and understand the impact of these scenarios. It will shed light on where the CRP is most effective and where there might be room for improvement in terms of program design to meet both economic and environmental goals more efficiently.

Spatial analysis of CRP outcomes under scenarios

Figure 1 represents the spatial implications of changes made to the CRP under various scenario analyses. The top map represents baseline enrollment depicting the geographic distribution of acreage enrolled under the current CRP baseline scenario with a 50% acreage constraint. The shades of green illustrate the intensity of enrolled acres across the United States, with darker greens indicating higher acreage enrollments. This provides us with a reference for understanding the spatial impact of the CRP as it currently operates.

The second map displays the differences in acreage enrollment between Scenario 1 and the Baseline scenario. The color scale ranges from green to red, where green areas signify counties where Scenario 1 resulted in more acres being enrolled compared to the Baseline, and red areas indicate fewer acres enrolled under Scenario 1. This highlights the regions where modifications under Scenario 1 lead to an increase or decrease in terms of CRP participation, reflecting the scenario's focus on a benefit-minus-cost analysis that may favor areas where conservation provides greater environmental returns per dollar spent.

The third map compares the Baseline scenario with Scenario 2. Under Scenario 2 the spatial distribution shows how financial incentives could alter landowner participation in the CRP. Regions that see an increase in green are possibly those where landowners find the new carbon-related payments more attractive, while areas in red may not find these changes as advantageous, possibly due to existing land use value or lower carbon sequestration potential.

Figure 2 represents the spatial implications of changes made to the CRP under the alternative baseline, scenario 3, and scenario 4. For acreage under the alternative baseline this map shows the acreage enrolled under the alternative baseline across the United States with a 50% budget constraint in place. The green areas represent higher enrollment under the budget-constrained scenario and set a baseline for understanding how a fixed budget influences CRP enrollment across different regions.

The second map illustrates the difference in acreage enrollment between Scenario 3 and the alternative baseline. Since Scenario 3 emphasizes the weight of carbon sequestration by inflating the N5d component, regions with increased green may represent a shift in enrollment to areas with high carbon-capturing potential.

The bottom map compares the changes in acreage enrollment under Scenario 4 to the alternative baseline. The areas with an increase in enrollment reflect the combination of cost adjustments and increased emphasis on carbon sequestration. This might redistribute enrollment to areas where the economic and environmental incentives of the CRP are maximized.

Overall, the spatial distribution in the maps reveals the heterogeneity of policy impacts across different regions. These maps illustrate that policy changes do not affect all areas uniformly; instead, they can have varied effects depending on regional characteristics such as agricultural productivity, land value, and potential for carbon sequestration. Ultimately, adjusting policy to emphasize carbon sequestration benefits could incentivize more CRP enrollment in areas with higher potential for carbon capture. Additionally, accounting for carbon credit payments could make CRP participation more appealing in some regions but less so in others, potentially due to varying economic returns from agriculture versus carbon credits. While some areas may see a significant impact, others might experience minimal or no change.

Environmental Benefit Change

Figures 3 and 4 showcase the percent change in total Environmental Benefits Index (EEBI) points for our scenarios under a 50% acreage constraint. Figure 3 shows the change between the baseline scenario and scenario 1 for environmental factors, with scenario 1 amplifying the weight of carbon sequestration by inflating the N5d component tenfold. Figure 4 shows the change between the baseline scenario and scenario 2 where scenario 2 reflects inflating the N5d component tenfold and \$15/Mg carbon payment subtracted from the rental payment. Each graph represents a different environmental component of the EBI, and the x-axis shows the percentage of total offered acreage. The y-axis reflects the percentage change in total EEBI points under the scenario.

From Figure 3 we see the effects of varying responses across different environmental benefit categories to the recalibrated weighting of carbon sequestration in scenario 1. Environmental components, such as those related to wildlife and soil erosion for instance, display some trade-off effects of increased carbon sequestration points. This suggests a trade-off when increasing emphasis on carbon capture and that bolstering the weight given to carbon sequestration could potentially divert focus from these other conservation priorities. For example, Changing land use to maximize carbon sequestration could involve converting areas that were previously diverse ecosystems into monoculture forests or grasslands, which might not provide the diverse habitat that various wildlife species require. Similarly, intensive afforestation can disrupt existing wildlife habitats that certain species depend on. Additionally, some carbon-focused practices may not always align with soil conservation. For instance, the choice of vegetation for carbon sequestration might not be optimal for soil health in all contexts. Certain fast-growing tree species used in afforestation might deplete soil nutrients more rapidly than native vegetation or might lead to increased soil acidification.

Conversely though factors such as surface and ground water quality and enduring benefits see a significant increase, signaling that this adjustment aligns with the aim of enhancing long-term environmental benefits, possibly through sustained carbon storage. This result seems to imply that Scenario 1 effectively promotes practices with enduring impacts, which could have significant positive effects on long-term sustainability and climate change mitigation. Carbon sequestration often involves practices such as afforestation or reforestation, cover cropping, and improved soil management. These practices can reduce runoff and erosion, which in turn helps in improving surface water quality by decreasing sediment and pollutant loads entering water bodies. Moreover, carbon sequestration practices that involve long-term changes to land use or management (such as establishing permanent forests or grasslands) inherently contribute to enduring environmental benefits. These practices not only capture carbon but also provide long-term habitat stability, improve soil structure, and increase biodiversity, which are recognized under the enduring benefits factor. Figures 4 reveals a similar effect on environmental impacts from Scenario 2. Similarly Figures 5 and 6, reflecting the scenarios under the budget constraint yield similar results.

Table 5 presents a correlation matrix of the environmental factors. The correlation matrix illustrates the relationships between various EEBI factors within the CRP. These correlation estimates can help us understand how different environmental components might influence each other when they are considered together in the program's evaluation process. In terms of the N5d (carbon sequestration) factor we observe a strong positive correlation of 0.78 with N4 (enduring benefits factor). This suggests that increasing the emphasis on carbon sequestration strongly aligns with long-term environmental benefits. The high correlation indicates that areas prioritized for carbon sequestration are also areas that contribute significantly to enduring benefits. The results also show moderate positive correlation (0.22 and 0.12) with N2b (Groundwater Quality) and N2c (Surface Water Quality). This indicates that there is some alignment between carbon sequestration efforts and groundwater quality improvements, suggesting that these environmental aspects may be complementary. Initiatives aimed at increasing carbon storage might also positively influence surface water quality, although the link is not as strong as with groundwater.

We observe a moderate negative correlation of N5d with N5a (Wind Erosion Impacts), N5b (Wind Erosion Soils), and N5c (Air Quality Zones). This negative correlation suggests that focusing more on carbon sequestration could potentially lead to less emphasis on controlling environmental aspects such as wind erosion, and that increasing carbon sequestration might detract from focusing on air quality zones, potentially impacting efforts to improve air pollution control.

Overall, the shifts in EEBI points across the various environmental factors suggest that inflating the carbon sequestration factor influences the CRP’s environmental priorities. While it bolsters the program's contribution to carbon storage, it has potential to also impact other environmental benefits. This intricate balance underscores the need for a careful, multifaceted approach in CRP policy adjustments to ensure that enhancements in carbon sequestration do not undermine other critical environmental benefits. The effectiveness and environmental impact of carbon sequestration practices depend heavily on how they are implemented. Variations in management practices, the ecological suitability of chosen methods for specific regions, and the balance between different conservation goals can all influence whether the outcomes are beneficial or detrimental to particular environmental factors.

6. Conclusion and Policy Implications

Our research presents a nuanced analysis of the Conservation Reserve Program's enrollment outcomes under various simulated scenarios, each offering its unique recalibration of the Environmental Benefits Index to integrate carbon sequestration more resolutely into the program's framework. The findings indicate that emphasizing carbon capture, while pivotal for climate change mitigation, introduces some trade-offs across other conservation priorities within the CRP. Our spatial analyses further unravel the heterogeneous impact of these policy adjustments across the United States, highlighting that the effects of CRP modifications are not universally felt but vary significantly based on a variety of regional attributes. These variations underscore the importance of a targeted approach and regional analysis in policy design that accommodates the diverse environmental and economic landscapes across different counties and states.

Moreover, our analysis of CRP enrollment data and subsequent simulations illustrate that high acceptance rates and EBI scores indicate a program well-aligned with environmental goals. However, integrating greater prioritized carbon sequestration into this equation requires careful consideration of how best to maintain a balance between all facets of environmental stewardship. While it is feasible for policymakers to adjust the weight of N5d to increase the carbon sequestration component of the CRP, such changes must be implemented thoughtfully and strategically, considering both the potential benefits and the complexities involved. The goal should be to enhance the program's effectiveness in climate change mitigation without compromising its capacity to meet other essential environmental conservation objectives.

This study advances our understanding of how conservation programs can evolve in response to climate change needs, particularly within the context of emerging carbon markets. It recommends a balanced approach that does not disproportionately prioritize carbon sequestration at the expense of other environmental benefits. Policymakers must recognize the intrinsic value of a multifaceted environmental agenda that sustains biodiversity, soil integrity, water quality, and air quality alongside carbon capture initiatives.

As the demand for environmentally conscious policies grows, so does the imperative need to evaluate and iterate our conservation strategies. Our research suggests that while pursuing carbon sequestration is vital, it should be within the broad spectrum of ecological benefits that conservation programs are uniquely positioned to deliver. The future of environmental policy, particularly within the framework of the CRP, lies in its adaptability and capacity to balance our ecosystems' diverse needs with the overarching goal of mitigating climate change.

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Table 1. Signup 54 Descriptive Statistics

Variable	Description	Average
n1	Wildlife habitat benefits (10 to 100 Points)	60.80
n2	Water quality benefits (0 to 100 Points)	55.02
n3	Erosion Factor (0 to 100 Points)	52.74
n4	Enduring Benefits (0 to 50 Points)	8.26
n5	Air Quality Benefits (3 to 45 Points)	16.41
n6	Cost	80.66
n1a	Wildlife Habitat Cover Benefits (10 to 50 points)	41.63
n1b	Wildlife Enhancement (0, 5 or 20 points)	6.69
n1c	Wildlife Priority Zones (0 or 30 points)	12.48
n2a	Location (0 or 30 points)	15.32
n2b	Groundwater quality (0 to 25 points)	8.84
n2c	Surface water quality (0 to 45 points)	30.86
n5a	Wind Erosion Impacts (0 to 25 points)	11.80
n5b	Wind Erosion Soils List (0 or 5 points)	0.16
n5c	Air Quality Zones (0 or 5 points)	0.31
n5d	Carbon Sequestration (3 to 10 points)	4.14
n5d10	Carbon Sequestration (30 to 100 points)	41.37
n6a	Cost (point value determined after end of enrollment)	75.62
n6b	Offer Less Than Maximum Payment Rate (0 to 25 points)	5.04
crpacre	number of acres enrolled	67.61
SRR	maximum county soil rental rate	98.29
offer	rental payment requested by landowner	94.81
ebitot	Total EBI points	273.89
total obs.	Total county enrollments under CRP Signup 54	56788

Table 2: Summary Statistics for Conservation Reserve Program: Signup 54 (2021)

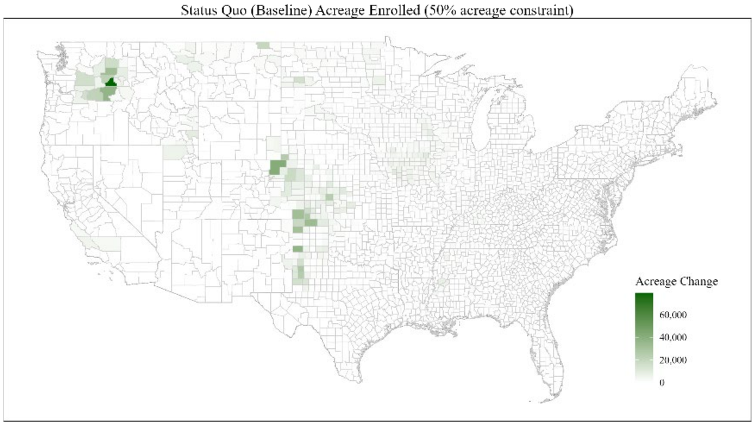
Signup 54 (2021)	Offered	Accepted
Total number of offers	56,788	51,610
Total acres (acres)	3,839,488	3,418,597
Average CRP rental payment ($/acre)	94.8	95.2
Average WASRR ($/acre)	98.3	98.7
Average EBI	273.89	282.02
Average EEBI	193.23	201.33

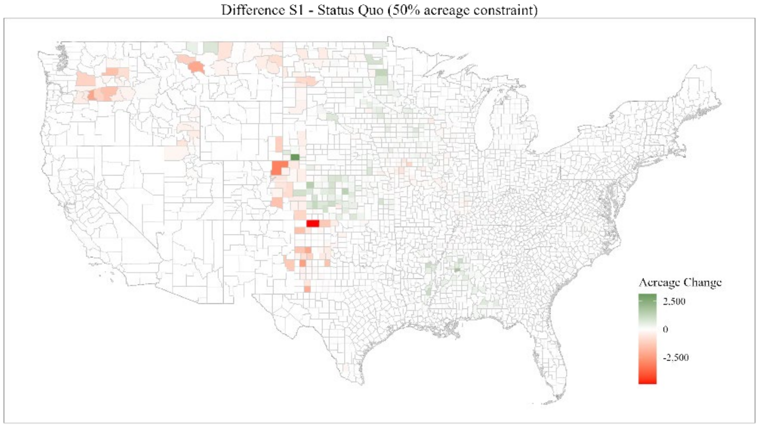
Table 3: Interpretation of EBI change under each Scenario

Status Quo	**Scenario 1**	**Scenario 2**
Baseline (EBI_0)	carbon sequestration points increased 10 times (EBI1)	carbon sequestration points increased 10 times; $15/mg carbon credit payment included (EBI2)
Alternative Status Quo	**Scenario 3**	**Scenario 4**
Baseline (EBI_3)	carbon sequestration points increased 10 times (EBI3)	carbon sequestration points increased 10 times; $15/mg carbon credit payment included (EBI4)

Table 4: Comparisons of Budgetary and Environmental Outcomes of CRP

(50% acreage constraint)	**% Change from Status Quo**		
Signup 54	**Status Quo (Abs Value)**	**Scenario 1**	**Scenario 2**
Total acres enrolled (million acres)	1.9	-	-
Total payment acres enrolled (million $)	112.7	2.27%	3.01%
Total EEBI acreage weighted points (millions)	403	-0.046%	-0.228%
(50% budget constraint)	**% Change from Alt. Status Quo**		
Signup 54	**Alt. Status Quo (Abs Value)**	**Scenario 3**	**Scenario 4**
Total acres enrolled (million acres)	3.1	-0.593%	-0.858%
Total payment acres enrolled (million $)	102.5	-	-
Total EEBI acreage weighted points (millions)	498	-0.117%	-0.465%





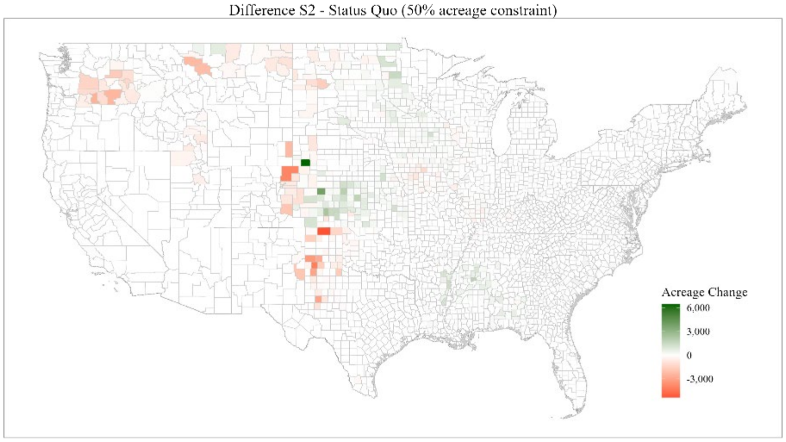
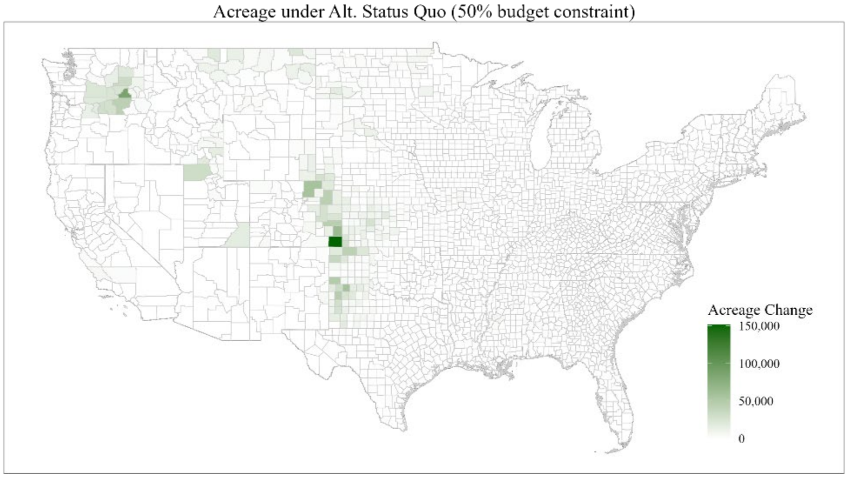
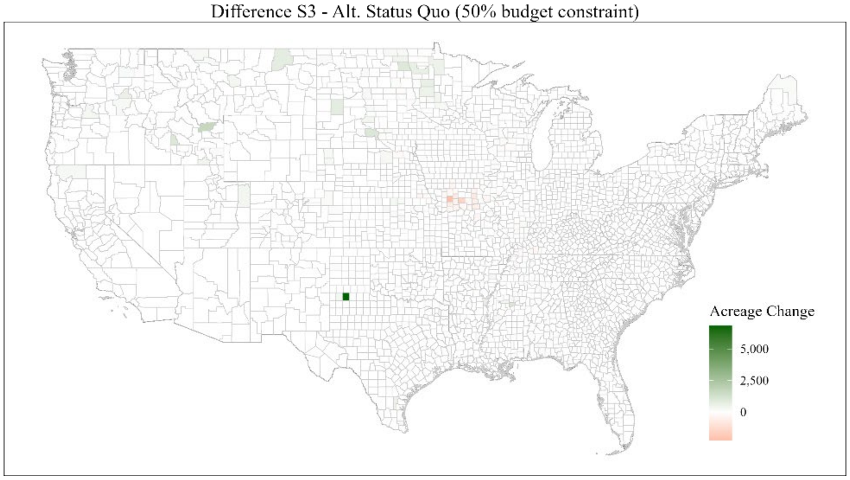


Figure 1 Acres Enrolled into CRP under Status Quo (Baseline) and Scenario Comparisons

Acreage under Alt. Status Quo (50% budget constraint)



Difference S3 - Alt. Status Quo (50% budget constraint)



Difference S4 - Alt. Status Quo (50% budget constraint)

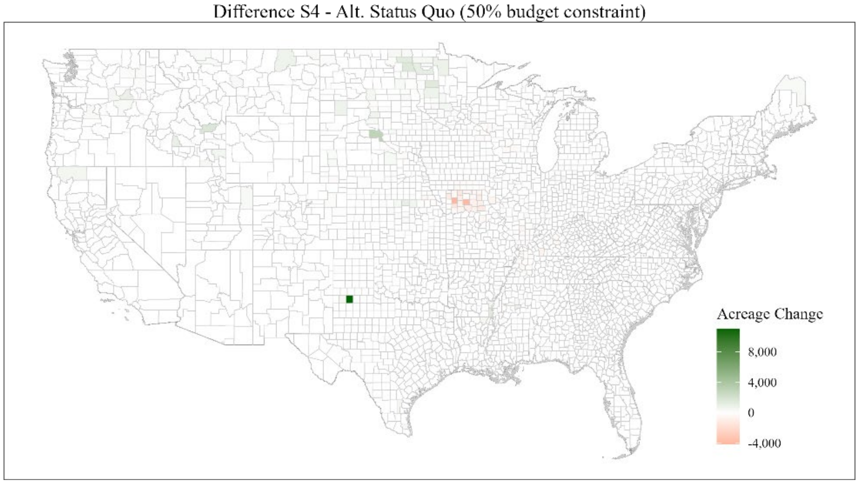


Figure 2 Acres Enrolled into CRP under Alternative Status Quo and Scenario Comparisons

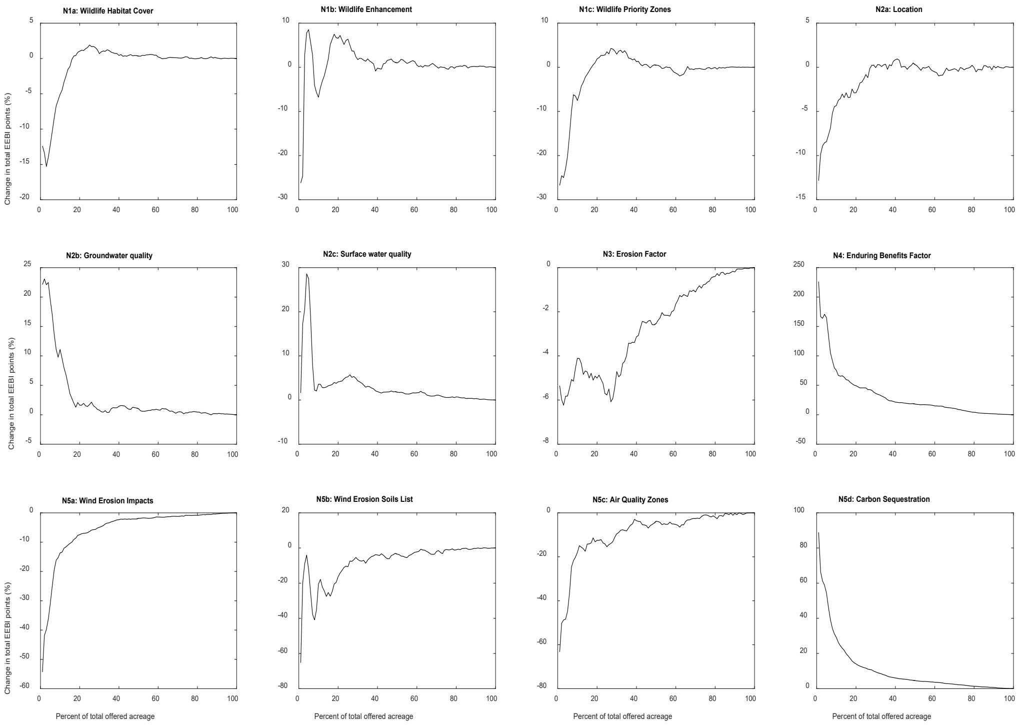


Figure 3: Percent change in Total EEBI Points under 50% acreage constraint

Note: Comparisons between Status Quo (baseline) and scenario 1 (10 times of N5d)

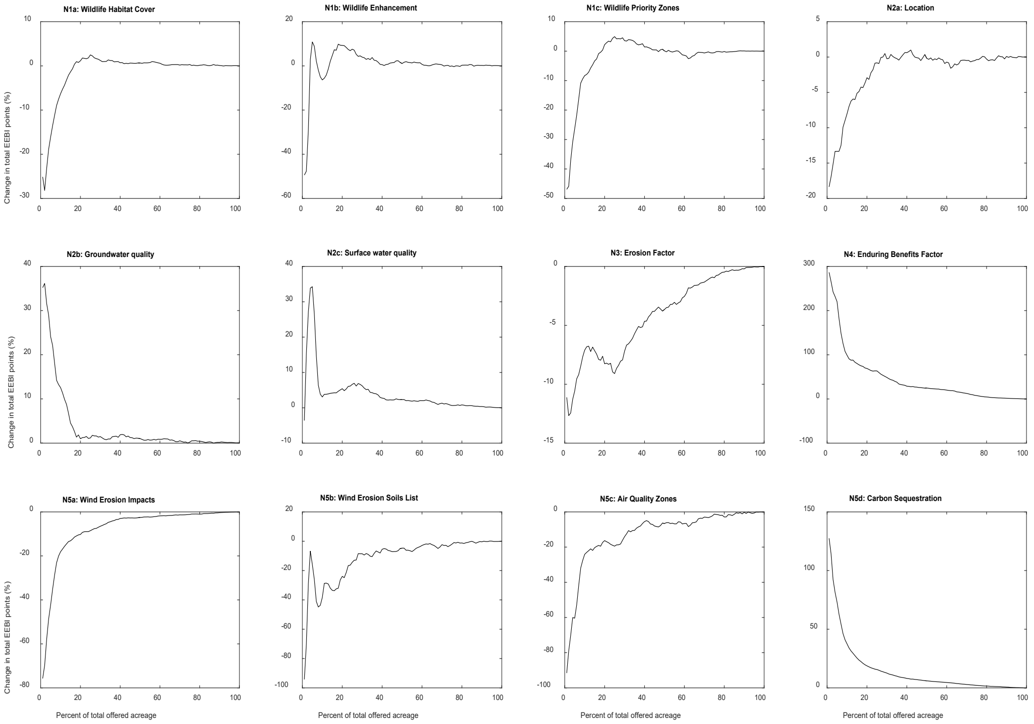


Figure 4: Percent change in Total EEBI Points under 50% acreage constraint

Note: Comparison between Status Quo (baseline) and scenario 2 (10 times of N5d) and carbon payment subtracted from rent.

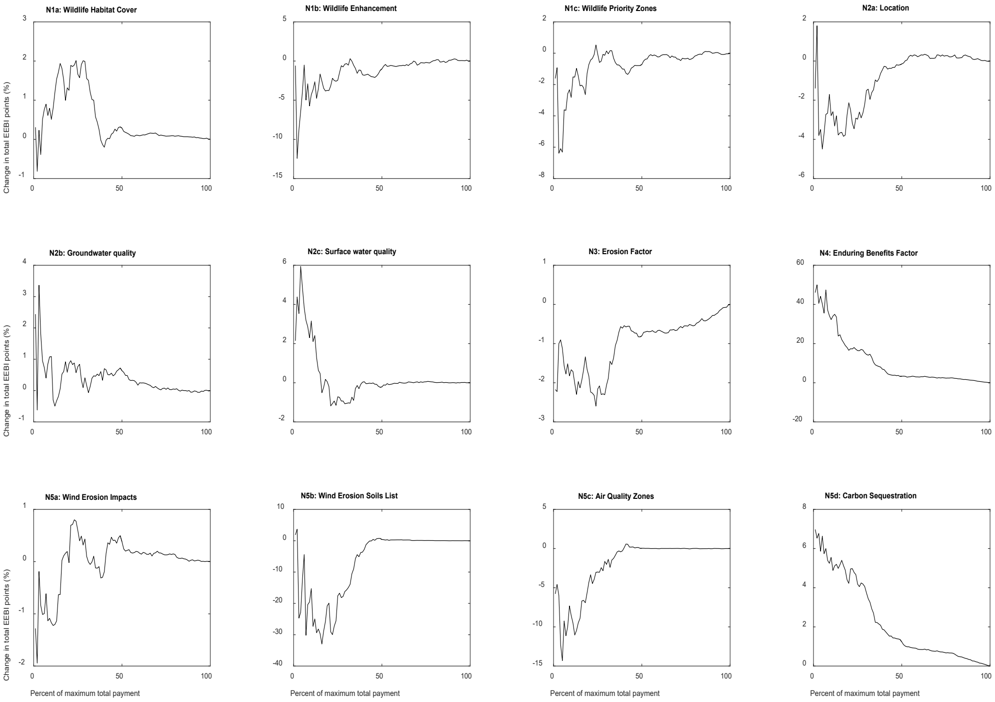


Figure 5: Percent change in Total EEBI Points under 50% budget constraint

Note: Comparison between Alternative Status Quo and scenario 3 B/C with 10 times inflated N5d vs. B/C without inflated N5d.

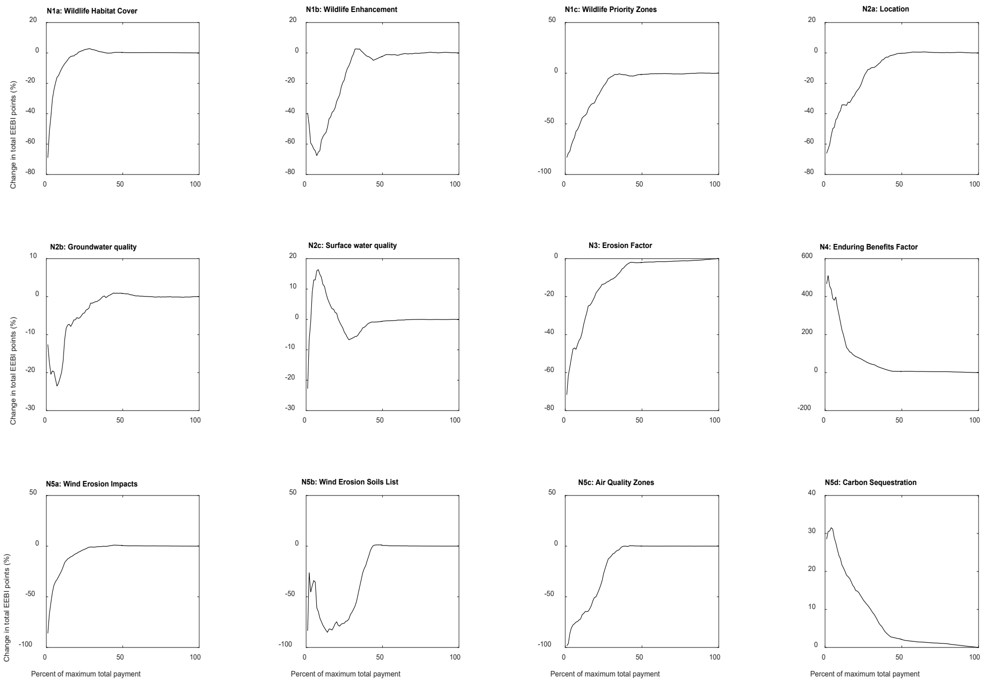


Figure 6: Percent change in Total EEBI Points under 50% budget constraint

Note: Comparison between Alternative Status Quo and scenario 4 10 times of N5d and carbon payment subtracted from rent.

Table 5: Correlation Matrix of EEBI Factors

	N1a	N1b	N1c	N2a	N2b	N2c	N3	N4	N5a	N5b	N5c	N5d
N1a	1											
N1b	0.30	1										
N1c	0.36	0.18	1									
N2a	0.01	0.03	0.73	1								
N2b	-0.08	0.03	-0.03	0.04	1							
N2c	0.11	0.24	-0.01	-0.04	0.31	1						
N3	-0.26	-0.08	-0.36	-0.30	0.18	0.26	1					
N4	0.21	0.18	0.07	0.03	0.11	0.20	-0.16	1				
N5a	0.09	-0.10	-0.01	0.00	-0.22	-0.31	-0.01	-0.17	1			
N5b	-0.11	-0.10	-0.08	0.04	0.04	-0.01	0.01	-0.11	0.09	1		
N5c	-0.10	-0.14	0.00	0.20	-0.02	-0.33	-0.01	-0.18	0.29	0.24	1	
N5d	-0.04	-0.01	0.02	0.05	0.22	0.12	-0.11	0.78	-0.35	-0.09	-0.15	1