Additionality, GHG Offsets, and Avoiding Grassland Conversion in the Prairie Pothole Region

Justin S. Baker, Ph.D., RTI International, justinbaker@rti.org
Annah Latané, RTI International, alatane@rti.org
Jeremy Proville, Environmental Defense Fund, jproville@edf.org
James Cajka, RTI International, jcajka@rti.org

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Introduction

Grassland ecosystems in the U.S. are currently being converted to crop cultivation at higher rates than seen in previous decades (Wright and Wimberly 2013; Lark et al 2015), and much of this conversion is concentrated in the Prairie Pothole Region (PPR) and surrounding states (including Iowa, Kansas, Nebraska, Minnesota, Montana, North Dakota, and South Dakota). There is concern that this conversion is being driven in part by biofuel polices (Hertel and Beckman 2012; NRC 2011; Schnepf and Yacobucci 2010;). There are also expectations that high commodity price trends will persist (Trostle 2010; Claasen et al 2011), meaning additional conversion and loss of grassland ecosystems could continue.

In addition to lost ecosystem services such as habitat preservation (Meehan et al 2010; Mushet et al 2014; Werling et al 2014) and water filtration (Donner and Kucharik 2008; Keeler and Polasky 2014), grassland conversion can result in the loss of soil organic carbon (SOC) (Fargione et al 2008; Gelfand et al 2011). Similar to deforestation, conversion of grassland to cropland results in an immediate release of carbon that has built up over several years (decades in some cases).

Greenhouse gas (GHG) offset payments focusing on the agricultural sector have been increasing in number in recent years. Several US-based carbon registries have been developing protocols that specify methodologies to estimate GHG emissions abatement from various activities or agricultural practices. In turn, this abatement can be monetized in the form of carbon credits. Typically, these registries - such as the Climate Action Reserve (CAR), the American

Carbon Registry (ACR) and the Voluntary Carbon Standard (VCS) – develop voluntary offsets that are purchased by an assortment of actors seeking to meet voluntary commitments. The methodologies and projects arising from these protocols are sometimes later adopted as compliance offsets in regulatory programs. For example, the California Air Resources Board (CARB) has ratified offsets for biogas digesters in livestock operations and forestry projects, which can then be purchased by firms regulated under California's statewide cap and trade regulation (AB32). A set of new protocols are currently being reviewed by CARB, including one for low-GHG rice cultivation practices that is expected to be adopted in June of this year (CARB 2014).

Further down the road for CARB, but currently in the pipeline for voluntary registries, are protocols surrounding the management of rangelands across the US (Diaz et al 2012). The most established of these focuses on the avoided conversion of grasslands to croplands; ACR finalized a methodology in October 2013 (ACR 2013), while the public comment process has recently taken place for CAR's version (CAR 2015). These protocols aim to incentivize landowners to avoid converting grassland systems by compensating them for maintaining the SOC levels that would be lost through crop cultivation. Avoided grassland conversion incentive structures are similar in scope to REDD+ programs that seek to reduce deforestation rates.

While GHG offset programs can potentially reduce grassland conversion rates, there are key difficulties in effectively implementing such programs, including how to define appropriate additionality criteria and determining the break-even price incentive necessary to encourage program participation across heterogeneous landowners. In the absence of meaningful additionality criteria, protocols essentially treat all grassland as eligible for program participation (which is unrealistic given the relatively low historic conversion rates). Establishing additionality criteria based on economic and biophysical factors can help limit total grassland area eligible for program participation, ultimately improving the effectiveness of the offset protocol. Identifying "hot spots" of high expected grassland conversion potential can be done by predicting differences in economic rents between cropland and pasture land uses. This is the approach taken by the protocols mentioned above, where eligibility is currently limited to areas where potential cropland rents exceed pasture rents by 40% or more. This is a practical approach to establishing meaningful additionality criteria. However, without appropriate parameterization, there is a very real risk of overpayment for given environmental outcomes by incentivizing nonadditional projects. This is especially pertinent in the case of this grassland conversions, which relates to land management decisions rather than structural or vegetative ones; Claassen et al (2014) have shown how these present a higher risk of nonadditionality. Conversely, setting additionality criteria too high could limit program participation and would not achieve the intended environmental objective of reducing grassland conversion rates. The analysis below delves into the implications and nuances of setting an appropriate additionality threshold within these offset programs.

Conceptual Model of Land Use Change and Establishing Additionality Thresholds

This analysis begins with a simple conceptual model of land use change from grassland to cropland based on expected economic rents and unobservable "hurdle" costs that influence landowner behavior. The model (presented below) provides a theoretical basis for an empirical case study in which we evaluate potential offset program costs and GHG mitigation potential with alternative protocol design parameters (focusing specifically on additionality criteria).

A standard approach for modeling the land use change decision is to compare the expected economic returns to alternative land uses, and the conversion costs required to move from one land use to another. Conversion costs can vary greatly from parcel to parcel, and can include multiple components, such as (1) cultivation or site preparation costs (the costs of preparing managed or native grassland for crop cultivation, or (2) hurdle costs, which are unobservable factors that influence a landowner's decision to convert or not. Hurdle costs could reflect a number of factors, including landowner's amenity value for maintaining natural landscapes/ecosystems, "heritage" value associated with consistent management of a parcel of land, risk aversion, or the real option value of switching land uses with uncertain future returns (referred to henceforth as "rents").

Thus, the economic decisions to convert from grassland to cultivated cropland for the i^{th} landowner can be expressed by Equation 1:

$$LandUse_i = \begin{cases} Cropland & \text{if } GrasslandRent_i + \mu_i + \rho_i \leq CroplandRent_i \\ Grassland & \text{Otherwise} \end{cases} \quad \text{Eq. (1)}$$

Where $GrasslandRent_i$ and $CroplandRent_i$ are the per-unit area expected economic returns in grassland and cropland, respectively, μ_i is the site preparation conversion cost (which could vary by parcel), and ρ_i represents average hurdle costs for the i^{th} farmer.

This model assumes that economic rents from both cropland and pasture (grassland) will increase with the quality of land, which can be determined by a number of factors related to soil quality, topography, and climate. Higher quality grassland or pasture implies higher forage yields, which implies potential for increased stocking rates, hay harvests, and higher economic returns per-unit area. Higher quality soils and favorable climate conditions will ostensibly help raise crop yields as well, generating higher returns in crop production. The relationship between $GrasslandRent_i$, $CroplandRent_i$ and overall land quality (denoted by the generic variable $\emptyset_i$, which can be interpreted as an index of land quality or crop suitability) is displayed graphically in Figure 1. In our simple model, we assume that cropland returns will increase more rapidly with land quality than pasture rents, resulting in much higher potential returns for higher quality land. Thus, soil quality and growing conditions are more important factors in determining potential economic rents for cropland than for grassland.

Figure 1 also suggests that cropland returns are theoretically lower than pasture returns for marginally productive lands. The costs of preparing low quality land for crop cultivation and the additional inputs required lead to low or (potentially) negative economic rents. These functional relationships can be used to predict grassland conversion at the point of intersection between the rent curves. Without considering land conversion or hurdle costs, one would expect the land use switch to occur at land productivity level $\emptyset_A$ when the theoretical returns are equal between cropland and pasture. Adding hypothetical (constant) values for μ_i and ρ_i, the expected switch point occurs at $\emptyset_B$. Thus, all land with assumed productivity potential greater than or equal to $\emptyset_B$ would be at risk of converting to crop production.

For grasslands with productivity levels that surpass $\emptyset_B$, avoided grassland conversion GHG offset incentives must equal the lost economic returns of converting land to crop production. Assuming some land productivity level $\emptyset_C > \emptyset_B$, Equation 2 displays the minimum offset payment necessary to maintain the land in its current (grassland) state:

$$MinOffsetIncentive_i = CroplandRent_i - (GrasslandRent_i + \mu_i + \rho_i) \qquad \text{Eq. (2)}$$

Dividing the minimum offset incentive by annualized CO_2 emissions from grassland conversion per unit area yields the break-even CO_2 price necessary to induce participation. Given the uncertainty and heterogeneity in land conversion and hurdle costs, recent protocol developers have considered use of a generic financial additionality parameter that restricts program eligibility to lands that can demonstrate that crop returns are 100+*X*% higher than grassland returns, where X represents the additionality threshold. For example, the California Air Resources Board is considering a 40% additionality threshold in its current draft protocol for avoided grassland conversion offsets.

This is a critical parameter, and if poorly developed could lead to inefficiencies for the voluntary market. Figure 2 elaborates on this point. Consider three additionality thresholds above the grassland rent total— α_{low}, α_{high} and α_{opt}. For the first case, α_{low}, the threshold is set too low; from a landowner's perspective, this would compensate for more than the difference between expected crop rents and total land conversion costs, which would lead to non-additional participation in the offset program. Also, since a large portion of the rent difference would be covered by the offset payment incentive in this scenario, the total costs of the program would be high relative to a program with an additionality threshold close to the optimal rate. If set too high, α_{high} would significantly lower total program costs, but could discourage program participation (thus encouraging land conversion) as the price incentive would not be sufficient to cover foregone economic opportunities.

Thus, the optimal additionality threshold, α_{opt} would be exactly equal to total conversion costs to cover the expected difference in rents above the parcel-specific costs of cultivating grassland. This is the point that theoretically ensures voluntary program participation and that grassland carbon stocks are maintained at parcel *i*:

$$\alpha_{opt} = 1 + \frac{\mu_i + \rho_i}{GrasslandRent_i} \qquad \text{Eq. (4)}$$

When economic rents and total conversion costs are known with certainty, then establishing parcel-specific additionality thresholds to minimize the costs of avoiding grassland conversion emissions would be trivial. Unfortunately, there is a great deal of uncertainty and heterogeneity regarding these key parameters, and establishing farm specific protocol parameters would incur high transaction costs. However, we can use this simple conceptual framework to conduct statistical simulations of avoided grassland conversion program participation across a range of assumed CO_2 prices and additionality thresholds using predicted (parcel-specific) economic rents and emissions. Results from these simulations provide insight into the implications of this key protocol parameter on program participation, avoided emissions, and total program cost outcomes. The following sections detail the empirical methods used in this paper before presenting results of the regional case study.

Methodology and Data

Using a spatially explicit dataset of cropland and grassland cover over three points in time (2001, 2006, and 2011), we develop empirical methods to (1) evaluate land use change trends over a five state area in and in close proximity to the PPR, (2) predict cropland and pasture economic rents, (3) use a logistic regression model to estimate the probability that grassland parcels will convert to cropland, and (4) estimate total program costs and avoided emissions with various program design parameters, including several additionality thresholds evaluated at incremental levels. Finally, we compare total costs and avoided emissions at different CO_2 price thresholds and evaluate the relative economic efficiency of these additionality criteria.

Land Cover Data Description and Methods

We evaluated net grassland conversion between 2001, 2006, and 2011 using the remote-sensed National Land Cover Dataset (NLCD) for five states in the PPR: Montana, North Dakota, South Dakota, Kansas, Nebraska, Iowa, and Minnesota (Wyoming has been excluded due to the large amount of federal- managed land) (Fry et al., 2011; Homer et al., 2007; Jin et al., 2013). This is a unique dataset as little empirical work has been published to date using the 2011 NLCD since it was recently released in April, 2014 and it allows us to identify grassland parcels that have converted during periods of relatively low and high returns to crop production. To create a parcel-level dataset of crop and grassland, we reclassified the full NLCD data into cropland (NLCD value 82), and general grasslands (NLCD values 52, 71, and 81) for each state for years 2001, 2006, and 2011. Note that this includes managed hay or forage systems, so we are capturing more than just conversion of natural grasslands. Areas of change/no change were then determined on a cell by cell basis (at 30x30 meter resolution). Each cluster of contiguous cells were converted into a polygon, and a centroid point was assigned to each cluster. The centroids were overlaid on a county layer, a growing season layer, a growing season precipitation layer, and a National Commodity Crop Productivity Index (NCCPI) layer. Areas with a high concentration of federally managed lands were excluded from the dataset.

Figure 3 and Figure 4 aggregate the polygon data to the county level to provide a general illustration of the extent of grassland cover and incidence of grassland conversion in recent years. Specifically, Figure 3 shows the total area in grassland by county in 2011. The largest concentrations of grasslands are in Montana, the Dakotas, and Nebraska. Figure 4 describes the net area of grasslands that has converted to cropland between 2001 and 2011. Net grassland conversion includes land that converted to crop production between 2001 and 2006 but then reverted to grassland by 2011. Note that areas in the darkest shades of blue have negative and zero values, indicating reversion back to grassland by 2011. Due to the limited observations of grassland conversion in Iowa and Minnesota, the remainder of this analysis did not include these states.

The NCCPI is developed and produced by the National Resource Conservation Service and provides a measure of the suitability of a parcel of land for crop production (NASS, 2010). NCCPI maps were pulled from the USDA-NRCS Soil Surveys Georgraphic Database (SSURGO, 2014). The NCCPI is chosen as the index of land quality for this analysis to maintain consistency with the theoretical framework. Figure 5 provides a map of the NCCPI data used in this analysis (aggregated to a county level). Note there is a great deal of variability in crop suitability, even within a state. The land cover polygons in the master dataset also include a single NCCPI value that was assigned after overlaying the SSURGO data onto the NLCD dataset.

Analyzing the mean NCCPI for grassland converted to cropland between 2006 and 2011 confirms that converted land is on average more suitable for crop production than land that remains in grassland, as shown in Figure 6. There is a statistically significant difference in mean NCCPI for grassland that converted by 2011 and land that stayed in grasslands for the 5-state area, consistent with theory. Note, however, that economic theory also suggests that land most suited to crop production is also likely to be the most productive pasture land, and therefore would also command a higher pasture rent. This would represent a higher opportunity costs for converting to cropland, so any methodology used to understand economic drivers of land conversion should consider both crop and pasture rents, applied to the farm or parcel level to the extent possible.

Statistical Approach

Exploratory analysis of the land cover data confirms trends in conversion to cropland from grassland over the 10 year study period. We use a two-step statistical approach to better understand the potential area a protocol should cover and evaluate performance of additionality thresholds. First, we predict economic rents for cropland and grassland using a standard multivariate regression procedure. This rent-prediction model estimates county-level crop and pasture rents as a function of state-level indicator variables, average county-level NCCPI, the number of growing degree days, precipitation, and a pasture indicator variable, interacted with all other dependent variables, as shown in Equation 5. The regression equation was used to predict crop and pasture rents for each polygon in the dataset.

$$Rent = \beta_0 + \beta_1 NCCPI + \beta_2 NCCPI^2 + \beta_3 GDD + \beta_4 GDD^2 + \beta_5 Precip + \beta_6 Precip^2 + \beta_7 Pasture + Pasture * (\beta_8 NCCPI + \beta_9 NCCPI^2 + \beta_{10} GDD + \beta_{11} GDD^2 + \beta_{12} Precip + \beta_{13} Precip^2) + \sum_i \delta_i State_i + \sum_i \gamma_i Pasture * State_i + \varepsilon \quad \text{Eq.(5)}$$

Where i=State

Economic cash rent data for crop and pasture land was obtained from the USDA National Agricultural Statistics Service at the county level for the year 2009. The 2009 period provided the most complete set of available data (NASS, 2009), and occurred in the middle of the 2006-2011 period in which much of the grassland conversion occurred. While cash rent estimates might not fully represent the potential profitability of cultivated cropland or grazing lands, it is a reasonable proxy for this analysis, which is concerned with the relative difference in expected returns. Cropland rents represent a weighted average of irrigated and non-irrigated cropland according to the area of each in the county. Table 1 summarizes the average crop and pasture rents by state in the region of interest. Average differences in rent across states range between \$25 and \$35/acre, with the exception of Nebraska, where cropland commands an exceptionally high average rental rate due to widespread use of irrigation and ideal growing conditions for higher valued crops such as corn.

The climate variables are provided by the USDA Forest Service. The number of growing degree days is defined as the number of days a parcel reaches a temperature above five degrees Celsius accumulated during the frost-free period (Crookston & Rehfeldt, 2010a). The precipitation variable is defined as the amount of precipitation for the parcel from April to September (Crookston & Rehfeldt, 2010b)[1].

The regression output from the rent prediction estimation are in Table 2. Climate variables and NCCPI are shown to be highly significant in determining crop and pasture rental rates. Table 1 shows the difference between the predicted and observed rents for crop and pasture parcels; as NCCPI increases, it is clear that converted cropland commands a higher rent. Figure 7 presents observed and predicted crop and pasture rents for the total 5 state region plotted over NCCPI. In general, this figure demonstrates the trend presented in the conceptual model (Figure 1), as crop rents rise more rapidly than pasture rents with land quality. This relationship is also seen at the state level (Figure 8). While there is a great deal of variability in cash rents for cropland (especially in Kansas and Montana), crop rents generally lie above pasture rents and increase with NCCPI at a more rapid pace than pasture rents.

The second step of the analysis uses the parcel-level predicted rents in a logistic regression to determine the probability of a parcel converting as a function of the NCCPI and state fixed effects. While the NLCD data shows that conversion has occurred at fairly high levels during the period of evaluation and is expected to continue, examining the prediction probability

[1] We acknowledge the potential multicollinearity between NCCPI and the climate variables in our analysis, but this is a relatively minor issue. Including the additional spatially explicit variables helps to introduce additional variability in economic rents when we interpolate at each raster cell.

of parcels to convert can help protocols developers more carefully determine which areas should be targeted. Results of the logistic regression (Table 3) show that overall conversion from grassland to cropland is still a fairly low probability occurrence across the PPR. Figure 9 shows the average predicted probability of conversion by state. The average probability of conversion across the region of interest is approximately 24%, so converting managed or natural grassland systems is becoming a fairly high probability event in this region. Parcels in South Dakota are predicted to have a slightly higher probable rate of conversion (30%) than the rest of the region, while parcels in Montana have on average a 16% probability of converting**.**

Protocol Performance Evaluation

We use results of the regression analysis by using the spatially disaggregated predicted rents to calculate the break-even carbon price for each parcel that qualifies for program eligibility (based on the scenario-specific additionality threshold) at different emissions levels. The final dataset is used to compare total program costs, potential emissions savings, and relative efficiencies of the different additionality approaches.

In order to estimate potential emissions savings, a range of emissions values was estimated for each parcel based on Ogle et al. (2003). As grasslands store additional soil organic carbon (SOC) relative to cultivated cropland, conversion of grasslands to cultivated cropland will thus result in a loss of SOC as the soil reaches a new equilibrium level of SOC. Ogle et al. (2003) describes the equation and parameters necessary to estimate the equilibrium level of SOC in agricultural soils.

$$SOC = RC \cdot TF \cdot IF \cdot LUC \qquad \text{Eq. (6)}$$

Where:

SOC SOC per hectare.

RC	Reference carbon stock (Mg C) per hectare.
TF	Tillage factor to estimate impact of tillage on SOC.
IF	Input factor to estimate the impact of cropping inputs.
LUC	Land use change factor to estimate impact of land conversion.

The reference carbon stocks reported in Ogle et al. (2003) vary by soil type and climate region, while the remaining parameters are based on nation-wide estimates. Ogle et al. (2006) provides estimates for how the tillage factor and land use change factors vary by climate region. Based on these published values, we can estimate the mean difference between grasslands and cultivated croplands by soil type, climate region, tillage type, and cropping input (Table 1). Assuming the estimates in these papers have an asymptotic normal distribution, we can use the published standard errors to estimate confidence intervals around the mean difference, which is how the low and high emissions totals are calculated for each parcel around the mean.

As described in the conceptual model section above, establishing additionality criteria in avoided conversion protocols is extremely difficult. Full additionality implies that only farms that would have converted under business as usual conditions are eligible to receive carbon offset payments. In addition to restricting *who* is eligible, additionality thresholds can be used to restrict *how much* they are compensated. We propose an approach that imposes additionality thresholds based on observed or predicted differences in crop and pasture rents similar to Diaz et al., 2012. This approach is appealing because we can observe/predict rents and use the additionality criteria to calculate a break-even carbon price. We can adjust the previous land use change decision criteria (Eq. 1) to the following form:

$$LandUse_i = \begin{cases} Crop \quad \text{if} \quad GrasslandRent_i * \alpha + P_{c,i} * Emit_i < CroplandRent_i \\ \qquad\qquad Grassland \quad \text{Otherwise} \end{cases} \qquad \text{Eq. (7)}$$

This replaces the unknown land conversion and hurdle cost parameters with two new terms:

α: Additionality threshold that establishes program eligibility based on the expected proportional difference in economic rents (as defined in the conceptual model section)

$P_{c,i}$ = Carbon price

Emit = Land use change emissions for parcel i

For example, a 40% additionality criteria says that only lands where crop rents are 40% higher would be eligible. In this case, $Additionality = 0.4*GrasslandRent_i$. Re-arranging terms from above, we can calculate the break-even carbon price for each parcel:

$$P_{c,i} = {(CroplandRent_i - GrasslandRent_i - Additionality)}/{Emit_i} \quad \text{Eq. (8)}$$

Finally, total costs for the parcel (annual) can be calculated by the product of the annual emissions factor and the carbon price. Economic returns are annualized using a 30 year discount factor at 4%. Total emissions are annualized over a 15 year return period (a standard horizon for soil organic carbon stocks to re-equilibrate following land use change), also using a 4% discount rate. Lands that converted to cropland by 2011 and lands with negative predicted rents are excluded from this analysis (as are certain counties with a high proportion of public lands).

Given recent concerns of grassland conversion in the PPR, it is important to evaluate various policy mechanisms for conserving grassland at risk of cultivation (including offset payments), and options for fine-tuning protocol design. Our analysis presents a detailed statistical methodology to estimate potential costs and mitigation potential of avoided grassland conversion offsets in the PPR. Additionality thresholds, henceforth referred to as rent difference thresholds (RDTs) were evaluated in ten 20% increments from 0.2 to 2. This is a reasonable range for potential RDTs given the large difference in observed crop and pasture cash rents. To put results into a policy context of mitigation potential and avoided land conversion at different price points, results were calculated at break-even carbon prices of $10, $20, $30, and $40/t$CO_2$eq. Results are available for the low, average, and high emissions factors, we focus primarily on the “average” emissions results in detail below.

Using a range of simulated prices from 10-40 $/t$CO_2$e allows us to provide a balanced discussion representing a variety of potential demand-side scenarios. Currently, carbon prices for Allowance Futures in California (typically the target market for the aforementioned protocols) are trading at approximately 12 $/t$CO_2$e (CPI 2015). This has more or less been the representative price level since August 2013. For this reason one might attribute greater credence to our ‘low carbon price’ set of results assuming 10 $/t$CO_2$e. Nonetheless, our ‘high price’ set of results serve as a basis for comparison, in cases where, for example, credits would be sold in voluntary or other markets, or perhaps a policy shift occurs in California’s cap and trade program and prices rise. It is unlikely that CO_2 prices in the California market will rise substantially in the foreseeable future, so the CO_2 prices chosen for this analysis represent a theoretical upper-bound price incentive for farmers.

Discussion - Results and Policy Relevance

Figures 10-13 provides a panel of total program costs ($), avoided emissions (t$CO_2$e), and total program area (acres) for the four CO_2 price scenarios. Figures 14-17 provide the same information, only at the state level. We can use these figures to evaluate program performance and potential cost efficiencies of various additionality thresholds and CO_2 prices.

Figures 10-13 demonstrate that we find significant offset potential in a limited area of the country: 0.5-6 million tCO_2e/yr, on a corresponding land base covering 0.5-7 million acres.

Program costs also have a wide range, depending on underlying assumptions, spanning \$2-\$110 million/yr. Extracting greater meaning from these numbers requires taking a closer look at the sensitivities to the inputs of the simulation.

Importance of Additionality Thresholds

In most cases, total costs start to rise with the assumed additionality threshold before reaching a peak and declining. At lower CO_2 prices, this peak happens at higher assumed RDTs (1.8 and 1.6 for \$10 and \$20/tCO_2e, respectively). Here, the total costs begin to increase with the RDT as program area rises steadily. Since the CO_2 price threshold is low, this limits program enrollment for low RDTs given the high break-even price incentive needed at low RDTs. As this parameter is increased, more eligible land is able to enter the market at less than \$20/tCO_2e. While it is counter-intuitive that program area would increase with a more stringent protocol parameter, it is important to note that if we chose the maximum break-even CO2 price for this analysis to evaluate total *potential* costs, then program area would decline with the RDT. At higher CO_2 prices, total costs still increase initially as program enrollment increases, but the peak in total costs occurs at lower RDTs (1.2 and 0.8, respectively for \$30 and \$40/tCO_2e).

Note that although total costs peak and start to decline, in all cases total program area and avoided emissions continue to rise after costs fall. We can use this information to identify RDTs that maximize total program size and environmental outcomes while minimizing costs per unit of abatement (Figure 18). At lower CO_2 prices, this point occurs at a fairly high RDT (1.8), which decreases for the higher CO_2 price cases (1.4 for the \$30 and \$40/tCO_2e cases). This indicates a general bias towards higher RDTs in achieving a high performance for environmental outcomes and potential supply, accompanied with higher program costs. This result has two important iimplications—(1) an additionality threshold of 40% is likely set too low to encourage market participation at current market prices, and (2) an optimal program-wide RDT can be established that minimizes total costs per unit of abatement and maximizes total program size, but the size of this parameter should be adjusted with the carbon market. If the market price for CO2 were to rise substantially, the RDT should be adjusted downward to maximize program participation rates and avoided emissions.

Variation among Carbon Price Scenarios

The carbon price appears to be a key driver of variation in avoided emissions, program area, and especially total costs. The latter rises faster when moving towards higher prices – the effect of this can be easily perceived in Figure18, showing trends in average cost of abatement. With a carbon price of 10 $/tCO_2e$, cost of abatement stays relatively stable at the 5 $/tCO_2e$ level across all RDTs. However, at a high carbon price of 40 $/tCO_2e$, it becomes immediately apparent that there is a higher range in costs of abatement, dropping from 23.8 to 11.4 $/tCO_2e$ as RDTs increase. Here, a clear downward trend is found (as is the case for the 20 and 30 $/tCO_2e$ scenarios), again reinforcing the notion that higher RDT values are much more cost-effective.

While some policy makers might be inclined to focus heavily on the average cost of abatement metric in order to tailor RDTs correctly in an offset program, this should remain a secondary concern to maximizing environmental performance by setting RDTs to target the highest possible amount of avoided emissions. At very high RDTS, even though average abatement costs are lower, avoided emissions begin to drop off steeply past a value of 180% for lower carbon price scenarios, and 140% for higher ones.

State-level Trends

Region-wide results suggest that additional fine-tuning of the RDT parameter can improve performance of the offset protocol in terms of reducing cost and increasing abatement potential. State-level results provide insight into how the RDT could be set to encourage participation in the market and reduce additionality concerns relative to a region-wide parameter. Establishing state-level RDTs would more closely match the α_{opt} parameter for farms falling within a particular state.

Results show that the bulk of the program area and abatement is achieved in Kansas, North Dakota and South Dakota. Montana follows with a substantially lower mitigation potential, with Nebraska trailing with very limited potential. Mitigation potential is only limited in Nebraska due to the scenario design for this particular analysis. Abatement costs are quite high in Nebraska (averaging more than $40/tCO2e) given the high relative difference between crop and pasture rents. Crop rents are approximately 400% higher ($87/acre) in Nebraska than pasture rents on average. If higher CO_2 price thresholds were considered, then Nebraska would contribute a much larger share of total abatement.

Disaggregating results by state exposes additional subtleties in their distribution across RDTs. Kansas shows peak levels of avoided emissions at lower RDT levels (140-80% from low to high carbon price scenarios), whereas these are found to be higher for North Dakota (180-120%) and South Dakota (200-140%). Results suggest that there are possibilities to enhance market performance by setting region-specific RDTs, rather than global program-wide parameters. For instance, at $20/tCO2e, the optimal RDT is approximately 120% in Kansas, 160% in North Dakota, 180% in South Dakota, and 200% in Montana.

Optimizing Offset Market Performance and Recommendations

A clear overall inference from this analysis is that any offset markets surrounding avoiding conversion of grasslands must very carefully parameterize additionality thresholds to determine eligibility. Our RDT approach has shown evidence that setting high values (80-180%, depending on carbon price and state) is desirable. This is quite pertinent to the current voluntary protocols that have been released or are in development: some of these have employed a value of 40% which does not appear to be sufficiently high. Although we have only tested one of a multitude of parameters present in these protocols, we have shown that the scope and impact of a resulting market is extremely sensitive to selecting an appropriate additionality threshold. To truly determine how central this parameter is, more research is needed in order to establish the sensitivity of outcomes to other protocol variables.

If the additionality threshold parameters are optimized, in the eventuality of these protocols becoming compliance offset options for AB/32, they can potentially unlock a significant amount of supply and greatly assist California in meeting its GHG mitigation goals. According to our results for the relevant 10 \$/tCO_2e price level, this means setting the global RDT to 180%; at full enrollment, providing ~2.5 MMt-CO_2e/yr of potential abatement. This represents about one tenth of the expected mitigation to be achieved through the cap on the transportation and natural gas sectors, by 2020. Employing state-specific RDTs is able to unlock an additional ~0.4 MMt-CO_2e/yr of potential abatement. At higher CO2 prices, mitigation potential increases substantially, as do gains to a targeted state-level RDT.

Establishing state- or region- specific targets can lead to additional cost savings without limiting the eligible land base and mitigation potential. Using predicted probabilities of conversion could also help protocol developers target areas at greatest risk of conversion, which can help narrow the geographic scope of outreach and program solicitation efforts (leading to lower transaction costs). Thus, improving methods for estimating economic rents and conversion probabilities can help lower program costs and maximize mitigation benefits. These factors remain critical in ensuring the overall success of such offset protocols, both in terms of achieving intended environmental outcomes while minimizing costs and non-additional payments for conserving grasslands with low conversion risk.

This research provides a theoretical framework and a detailed statistical methodology to answer important questions surrounding outcomes for any environmental program focused on grassland conversions. This outlines two distinct and worthwhile future extensions of this work. The first would be to contrast these results to those obtained from other theoretical methods employing probabilistic (expected value) approaches, and/or using alternative input datasets (including land cover data). Secondly, empirically testing and validating our approach through field research and economic surveys would be valuable in solidifying the conclusions presented above.

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Figure 1: Conceptual diagram of method to project grassland conversion based on net economic returns

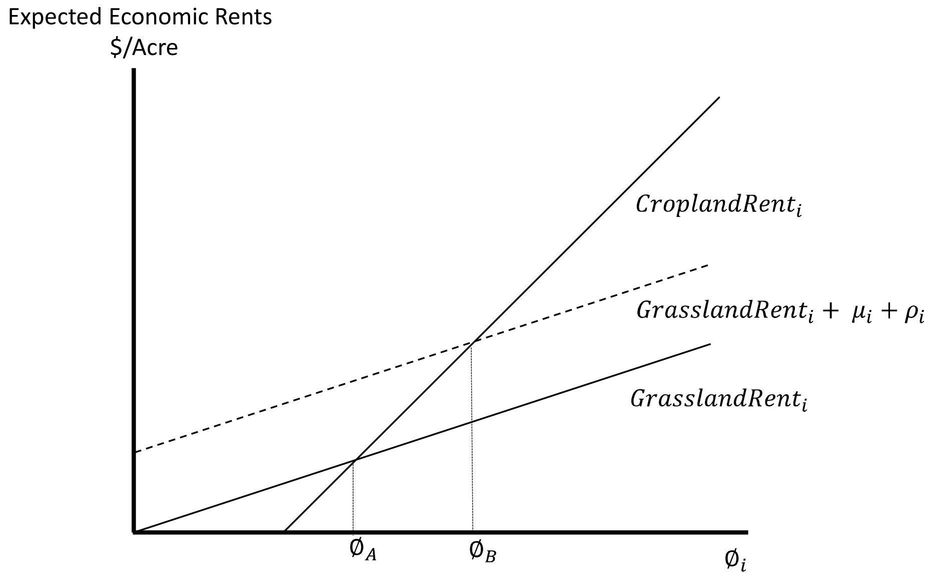

Figure 2: Illustration of additionality thresholds based on economic rent differences

Figure 3. Total Area of Grassland by County

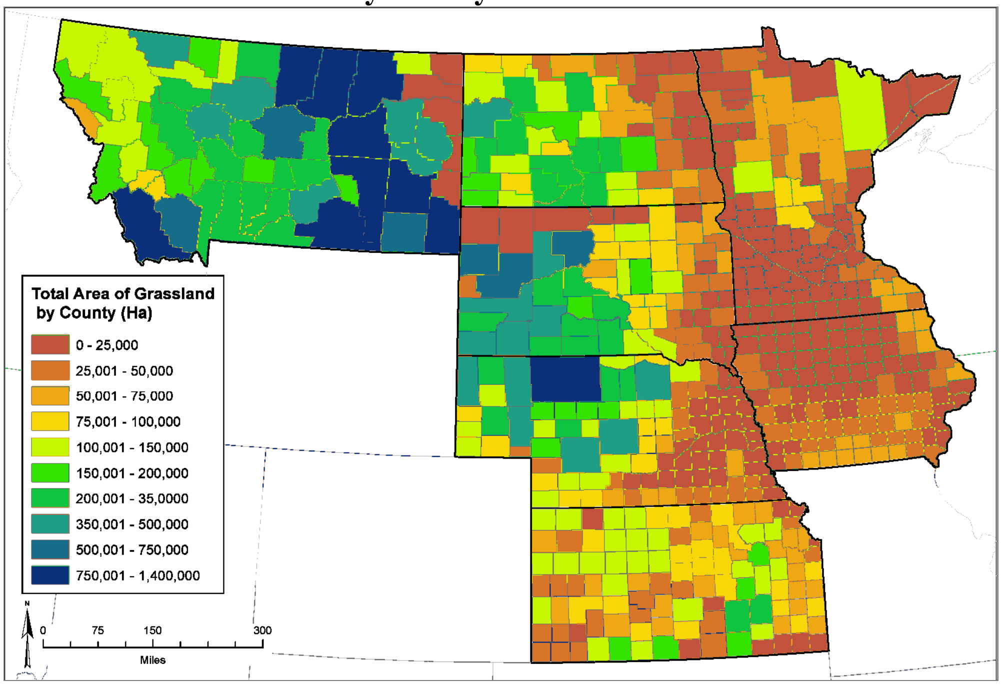

Figure 4. Net Area of Converted Grassland by County

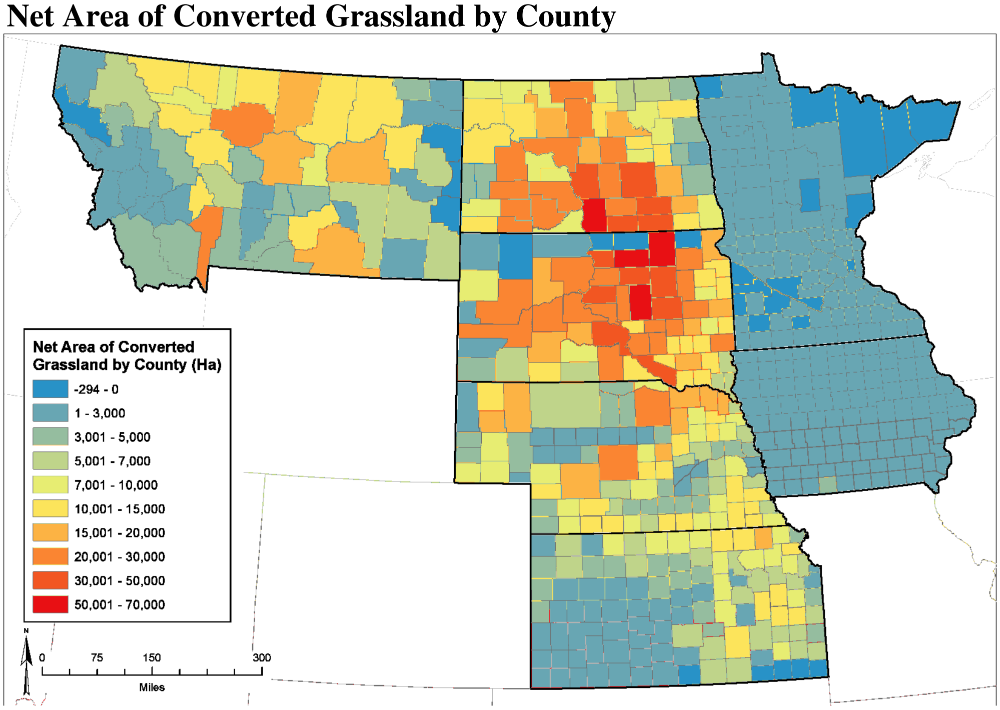

Figure 5. Average NCCPI by County

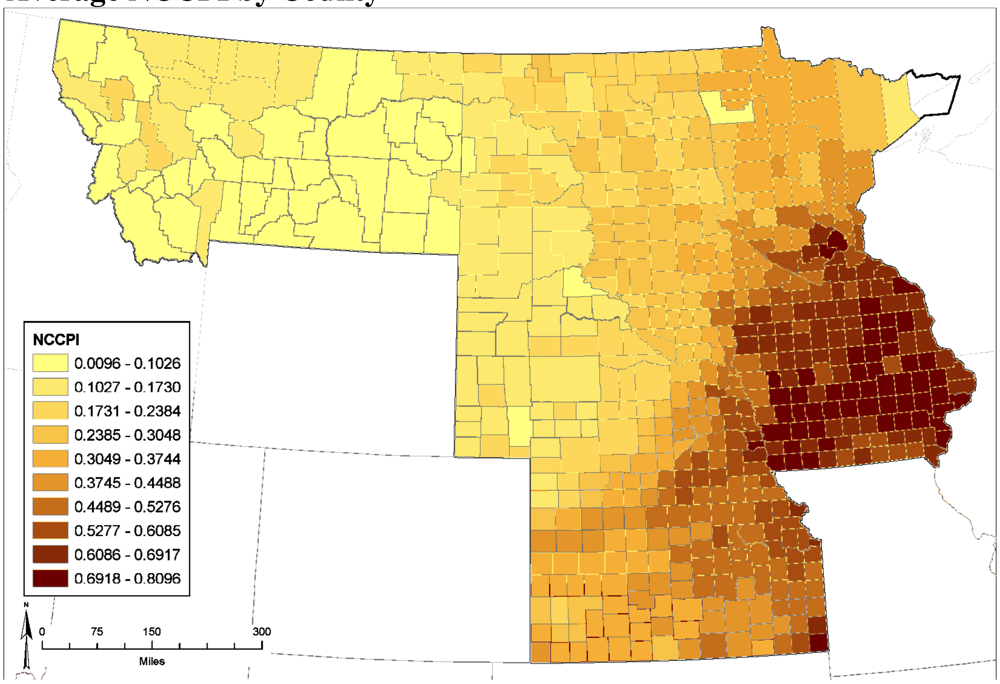

Figure 6. Mean NCCPI for Grassland and Cropland

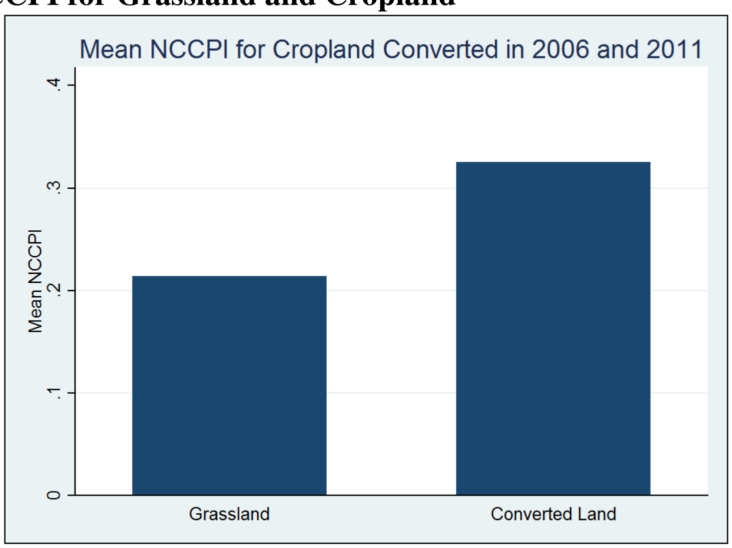

Table 1: Mean Cropland and Pasture Rental Rates and Mean Difference ($/acre)

State	Cropland Rent	Pasture Rent	Mean Difference
ND	40.42	14.66	25.73
NE	113.23	23.88	87.35
SD	62.54	26.94	35.60
MT	36.59	6.10	25.90
KS	44.26	15.74	28.76

Table 2: Rent Regression Results

	Coefficient	SE
NCCPI	213.6***	-40.6
NCCPI*Pasture	-168.3***	-46.44
NCCPI^2	-168.1**	-51.25
(NCCPI^2)*Pasture	151.1*	-63.1
Precipitation	0.743***	-0.101
Precipitation*Pasture	-0.521***	-0.122
Precip^2	-0.000625***	-0.000106
(Precip^2)*Pasture	0.000440***	-0.000127
Growing Degree Days	0.124***	-0.0199
(Growing Degree Days) * Pasture	-0.131***	-0.0211
(Growing Degree Days)^2	-0.0000276***	-0.00000413
((Growing Degree Days) ^2) * Pasture	0.0000291***	-0.00000466
South Dakota	-2.436	-3.636
(South Dakota)*Pasture	4.911	-4.324
Nebraska	19.87***	-4.387
Nebraska*Pasture	-25.37***	-5.114
Montana	36.99***	-4.392
Montana*Pasture	-35.82***	-5.114
Kansas	-43.36***	-5.884
Kansas*Pasture	27.47***	-7.666
Pasture	265.5***	-30.86
Constant	-308.0***	-26.64
* p<0.05, ** p<0.01, *** p<0.001		

Figure 7. Observed and Predicted Rents for Crop and Pasture by NCCPI

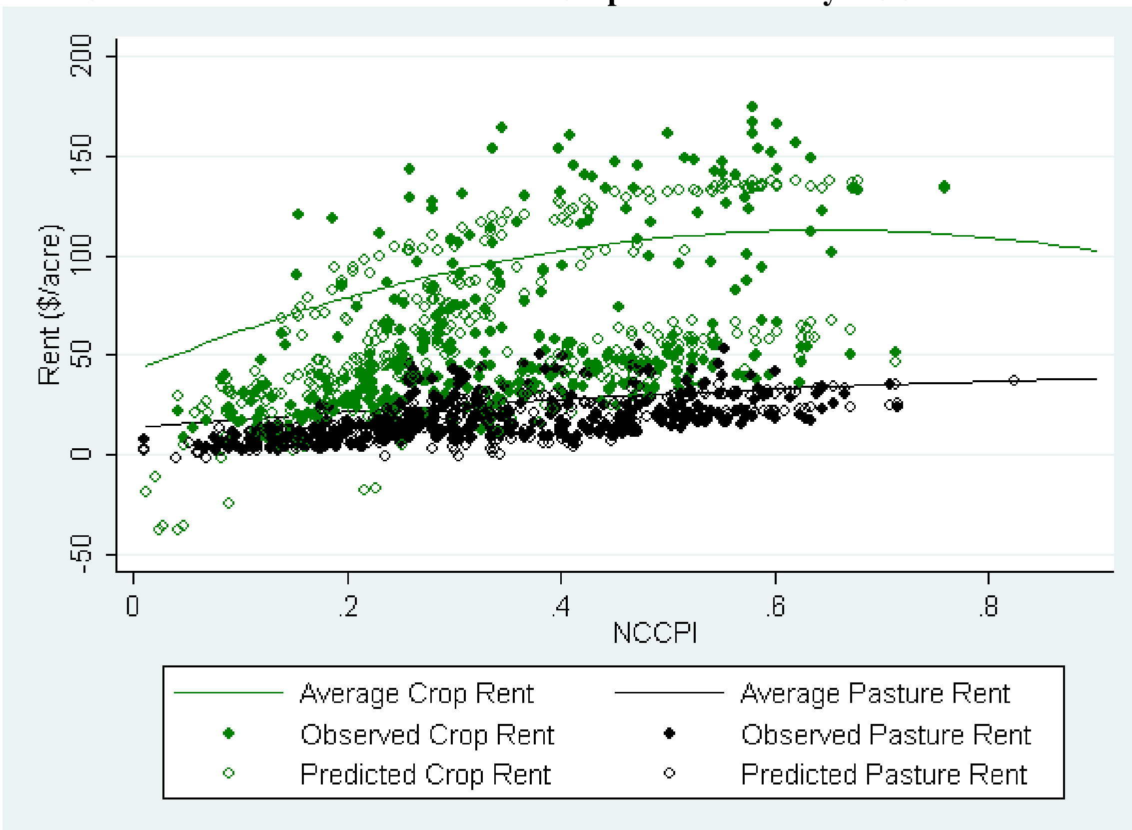

Figure 8. Observed and Predicted Rents for Crop and Pasture by State and NCCPI

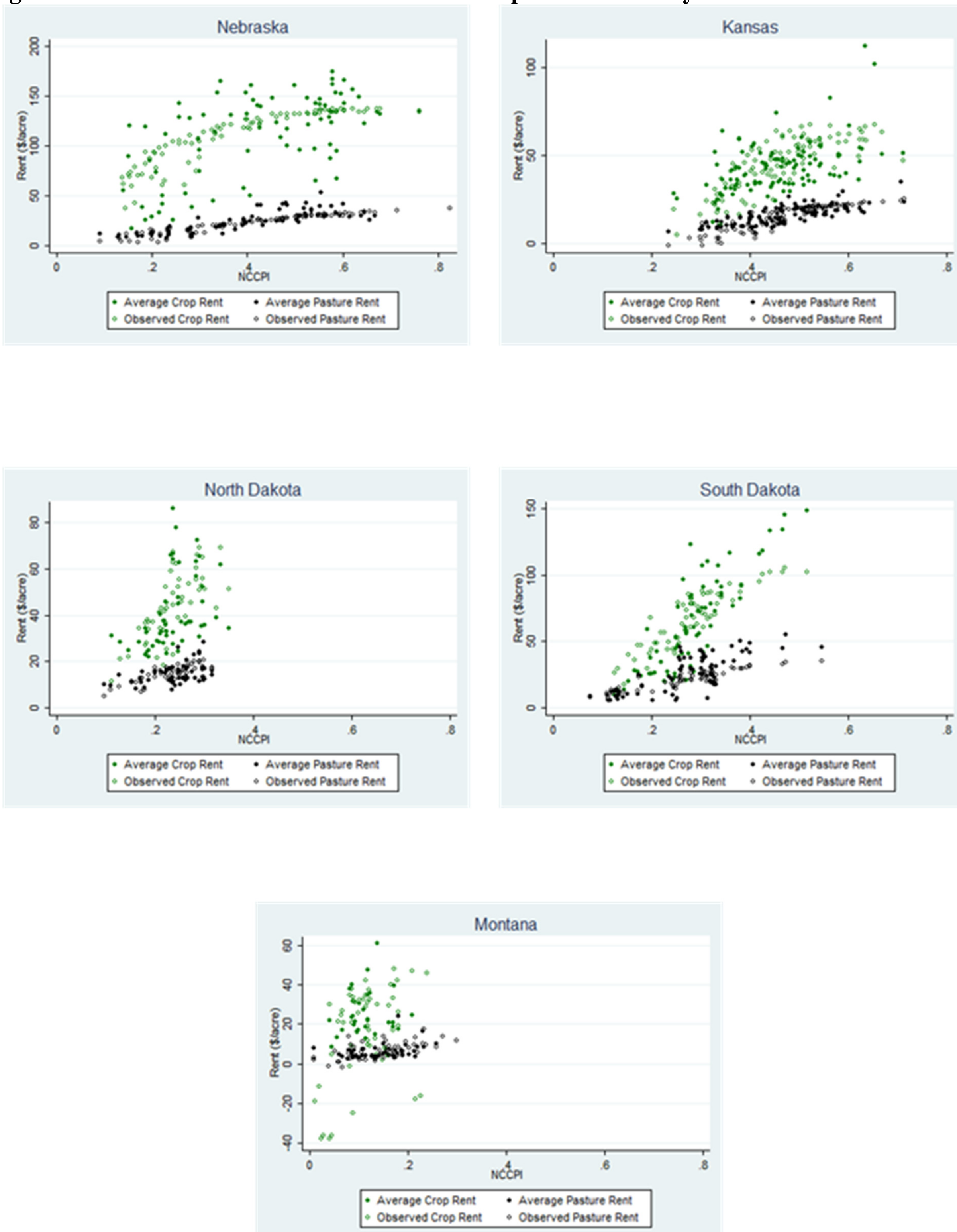

Table 3: Predicted Land Conversion Logistic Regression Results

Variable	Coefficient	SE
Rent Delta	0.0443***	-4.3E-06
Nebraska*Rent Delta	-0.0355***	-3.7E-06
South Dakota*Rent Delta	0.0107***	-3.3E-06
Montana*Rent Delta	-0.0225***	-4.6E-06
Kansas*Rent Delta	-0.0445***	-4.3E-06
Rent Delta^2	-0.000222***	-8.78E-08
Nebraska*Rent Delta^2	0.000269***	-8.50E-08
South Dakota*Rent Delta^2	-0.000254***	-8.11E-08
Montana*Rent Delta^2	0.00000472***	-1.2E-07
Kansas*Rent Delta^2	0.000737***	-1.1E-07
Constant	-2.056***	-5.2E-05
* p<0.05, ** p<0.01, *** p<0.001		

Figure 9: Average Predicted Probability of Conversion to Grassland by State

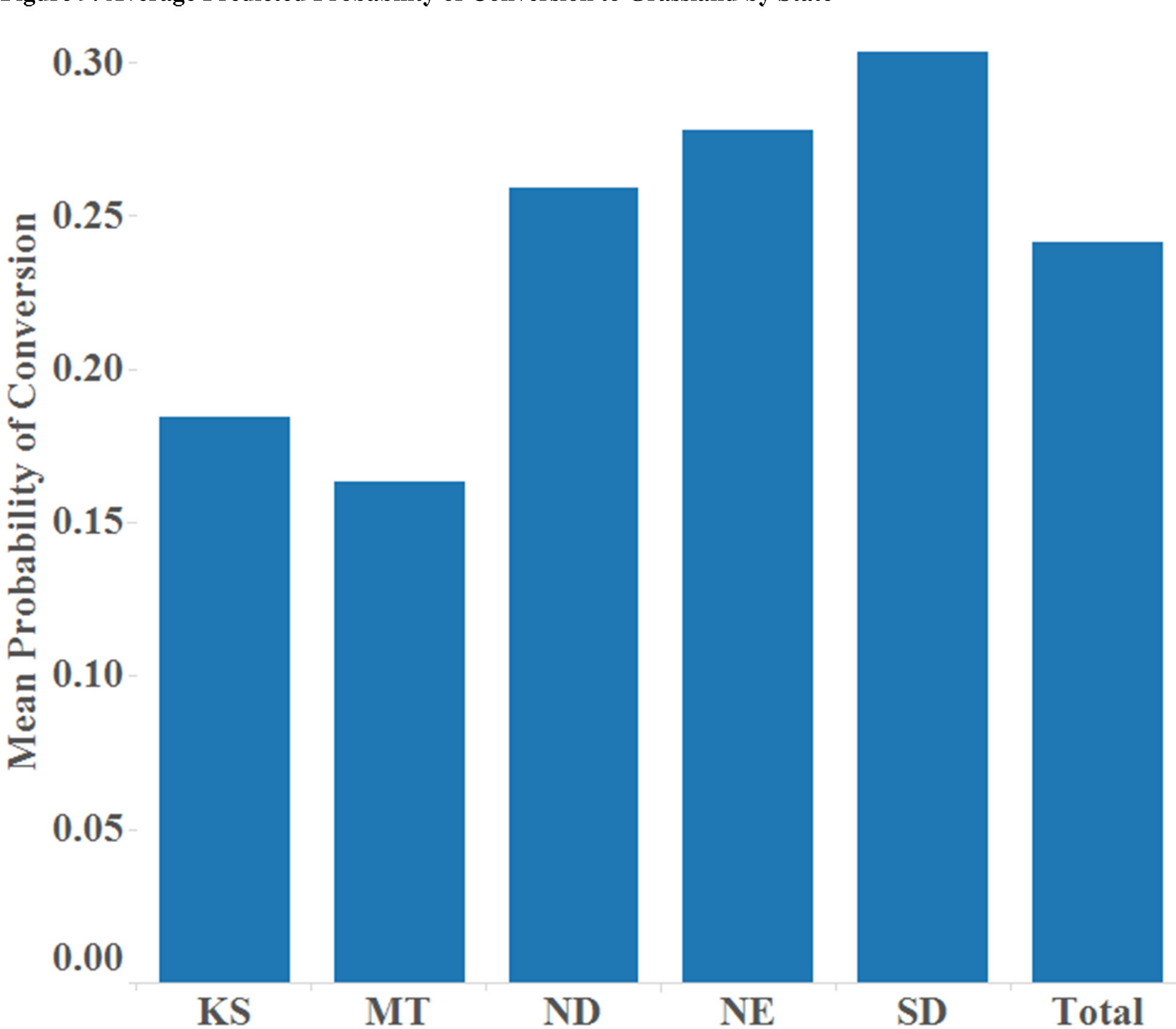

Figure 10: Total program costs, avoided emissions, and program area at $10/tCO2e

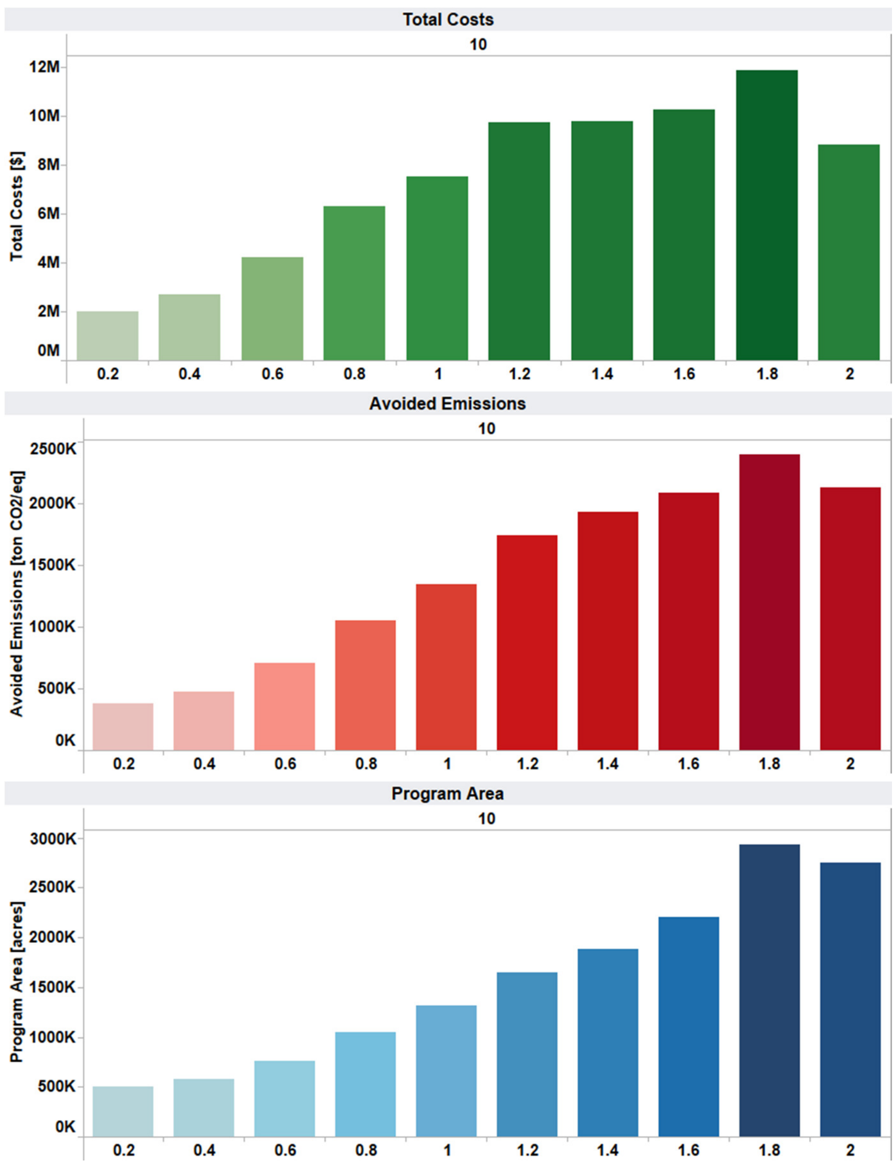

Figure 11: Total program costs, avoided emissions, and program area at $20/tCO2e

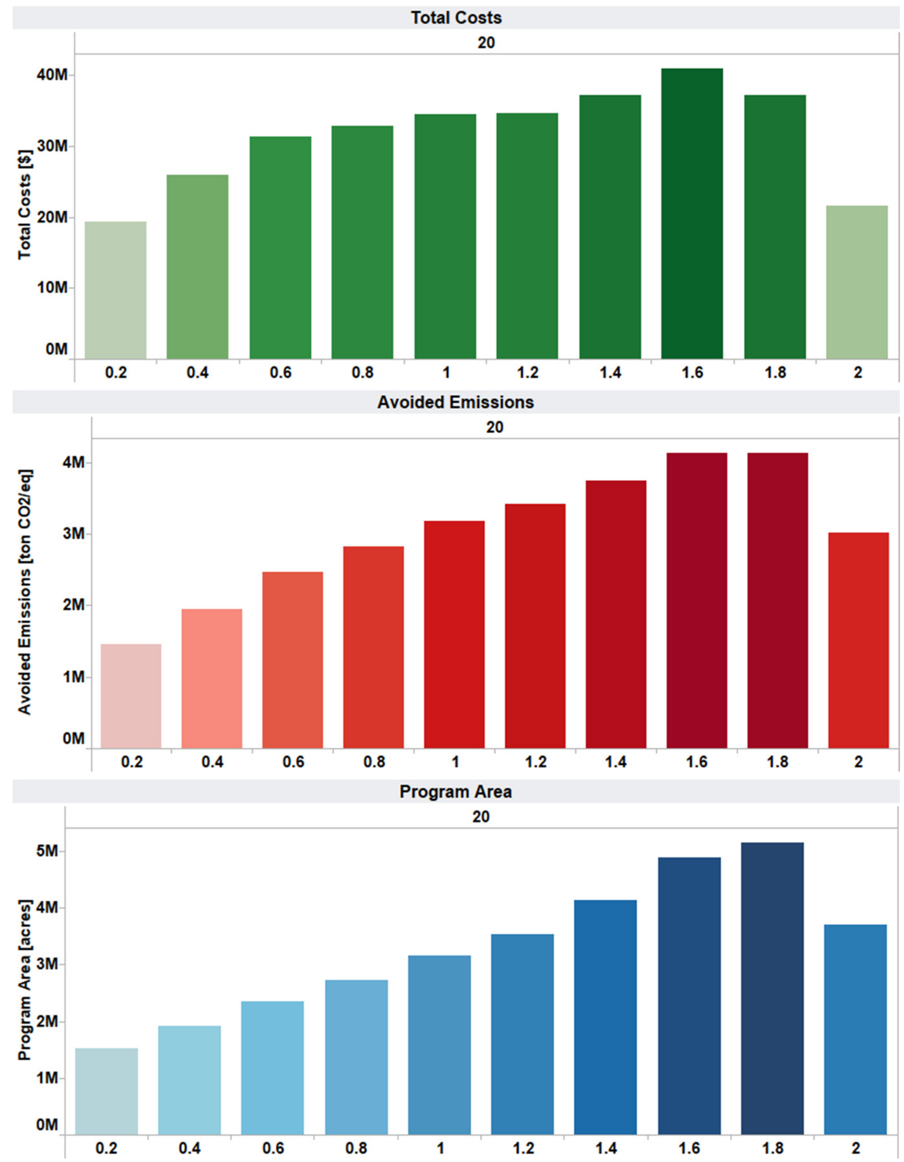

Figure 12: Total program costs, avoided emissions, and program area at $30/tCO2e

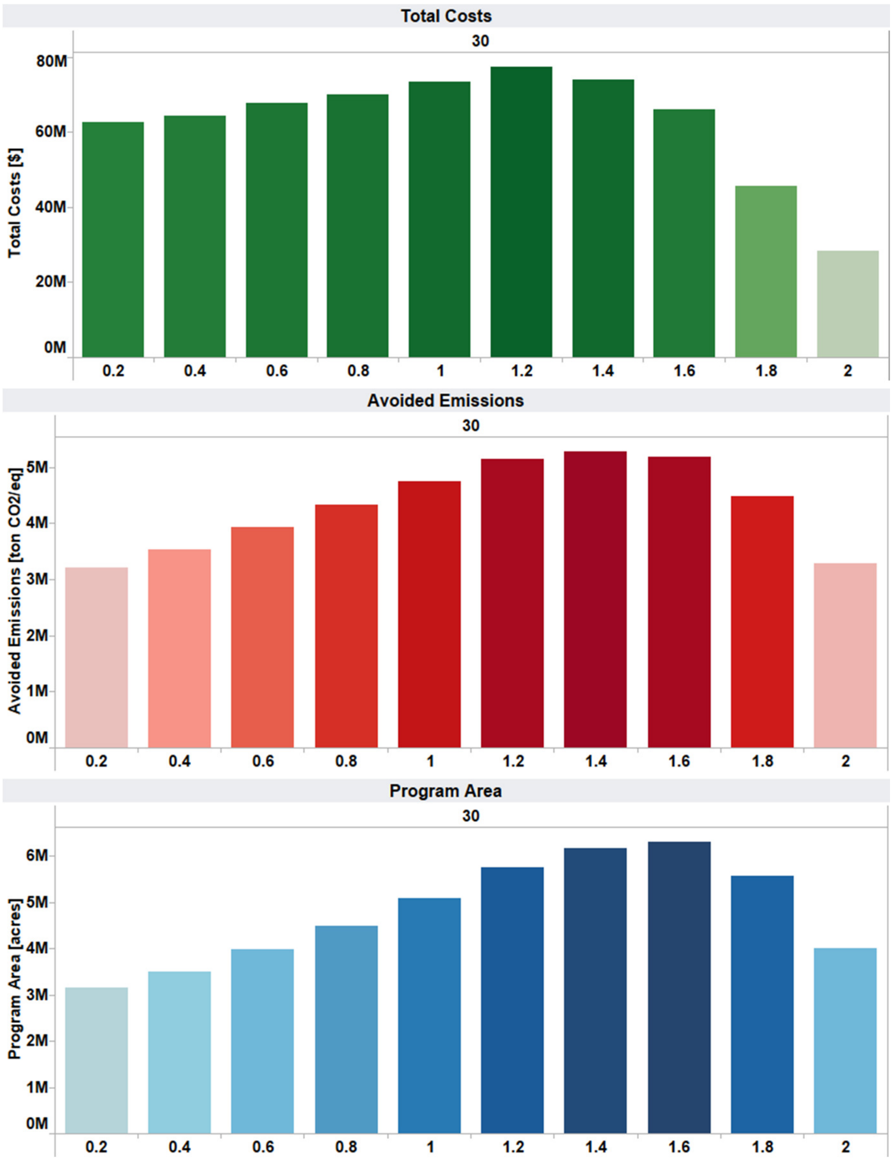

Figure 13: Total program costs, avoided emissions, and program area at $40/tCO2e

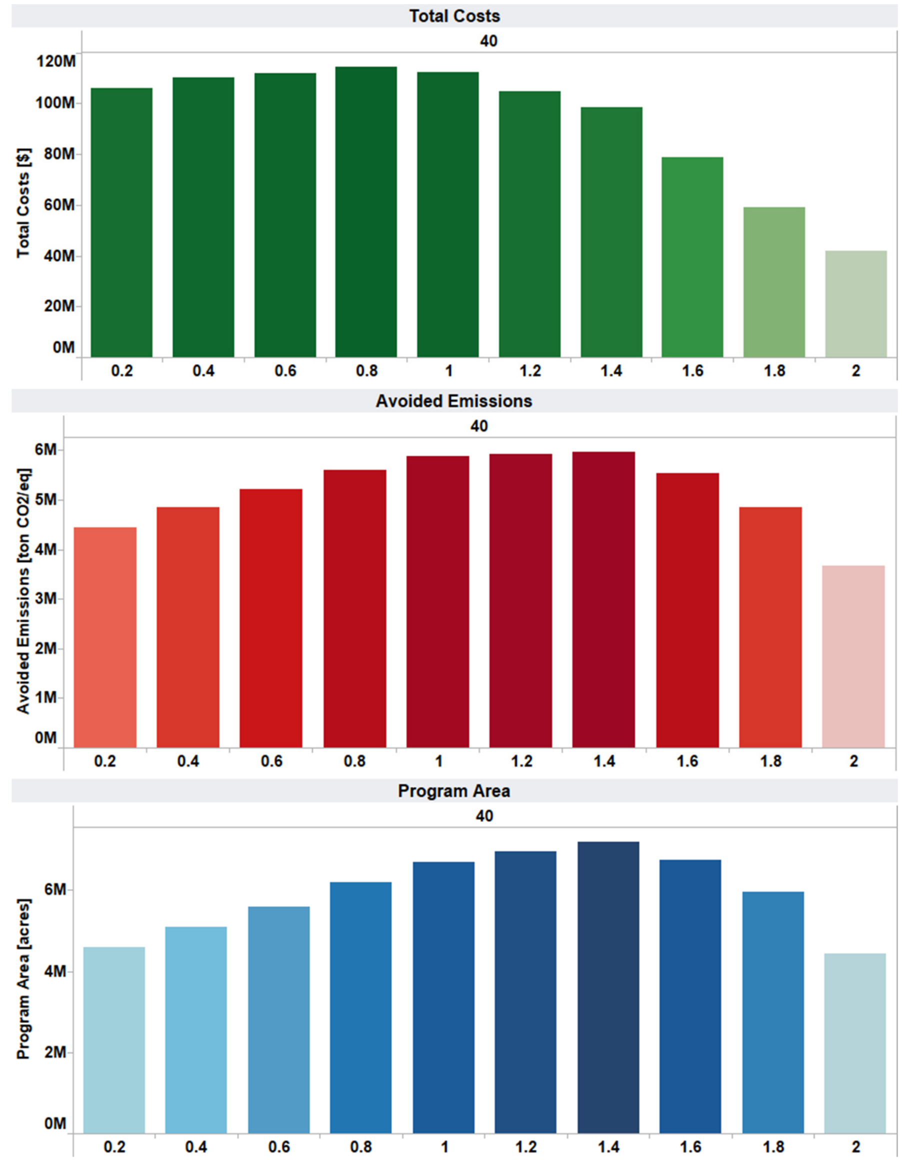

Figure 14: Total costs, avoided emissions, and program area by state at \$10/tCO2e

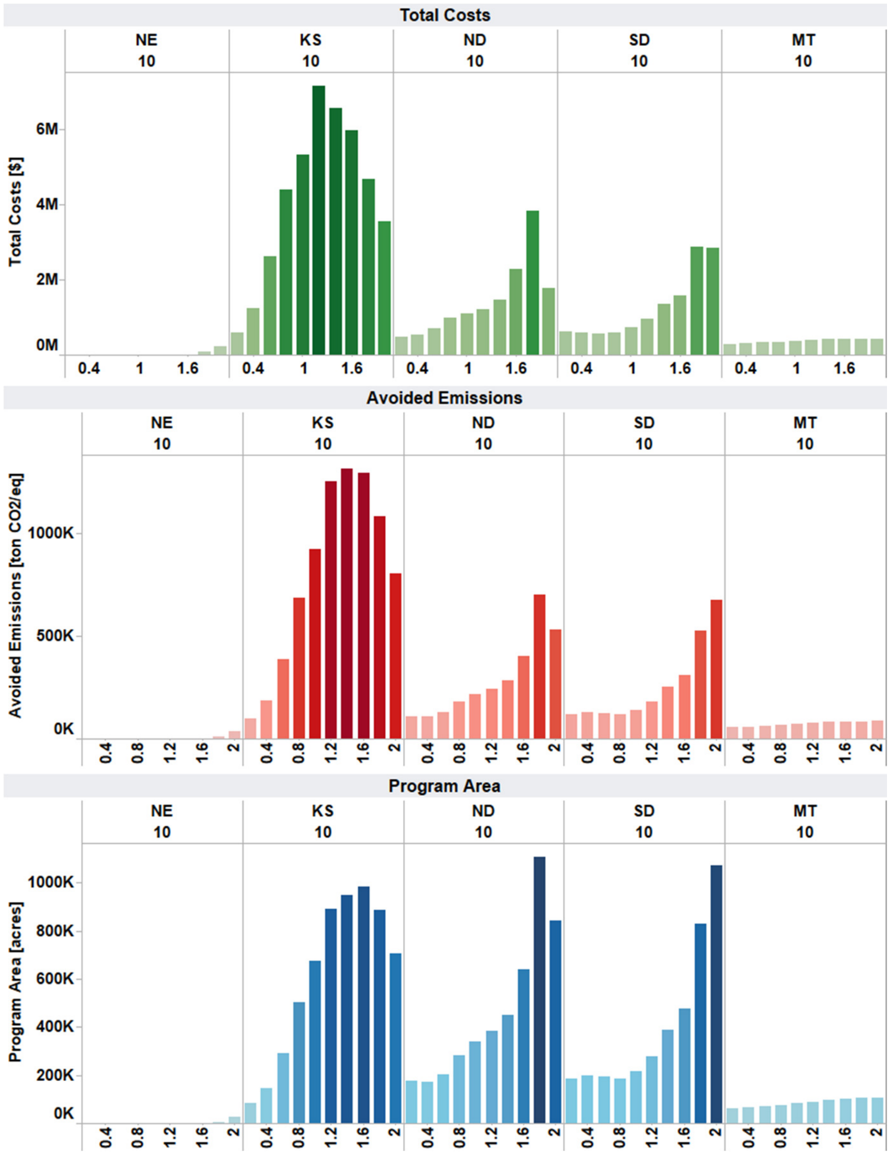

Figure 15: Total costs, avoided emissions, and program area by state at \$20/tCO2e

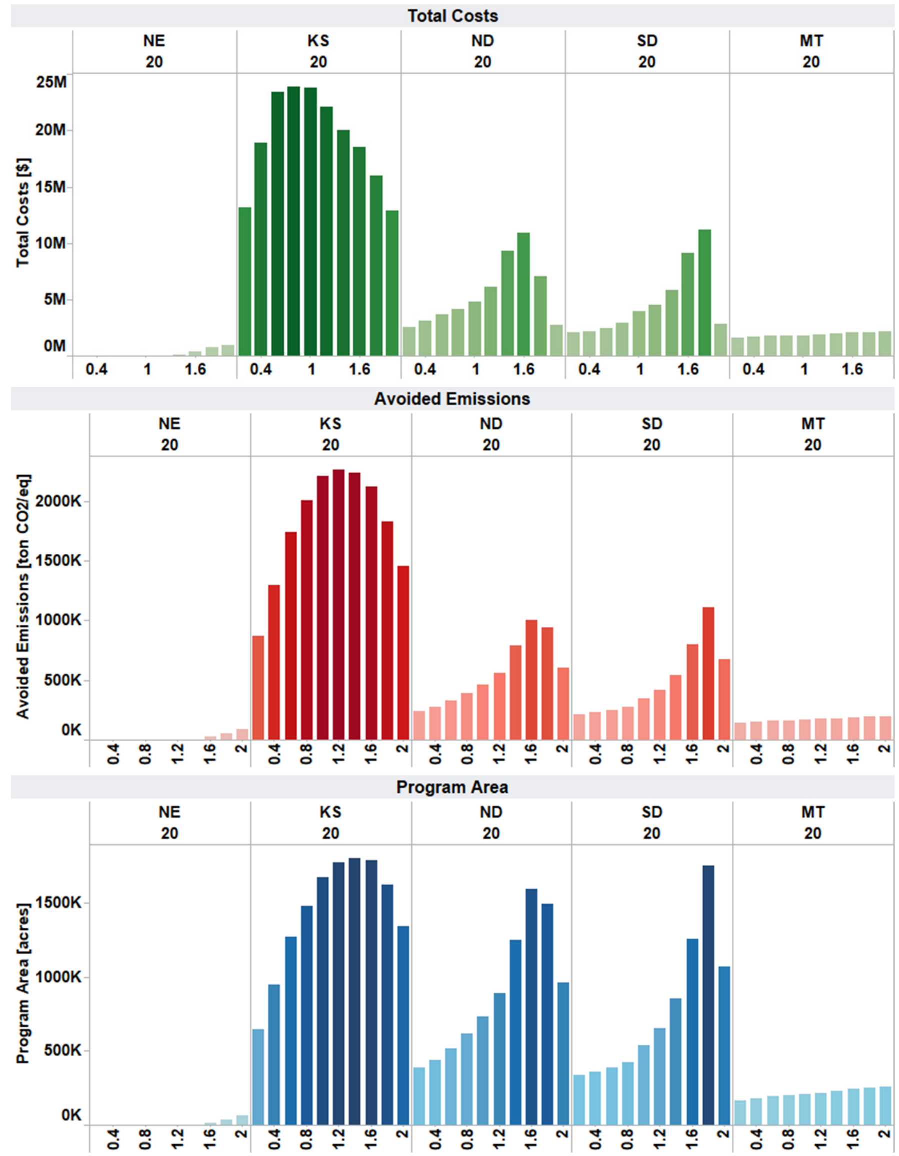

Figure 16: Total costs, avoided emissions, and program area by state at $30/tCO2e

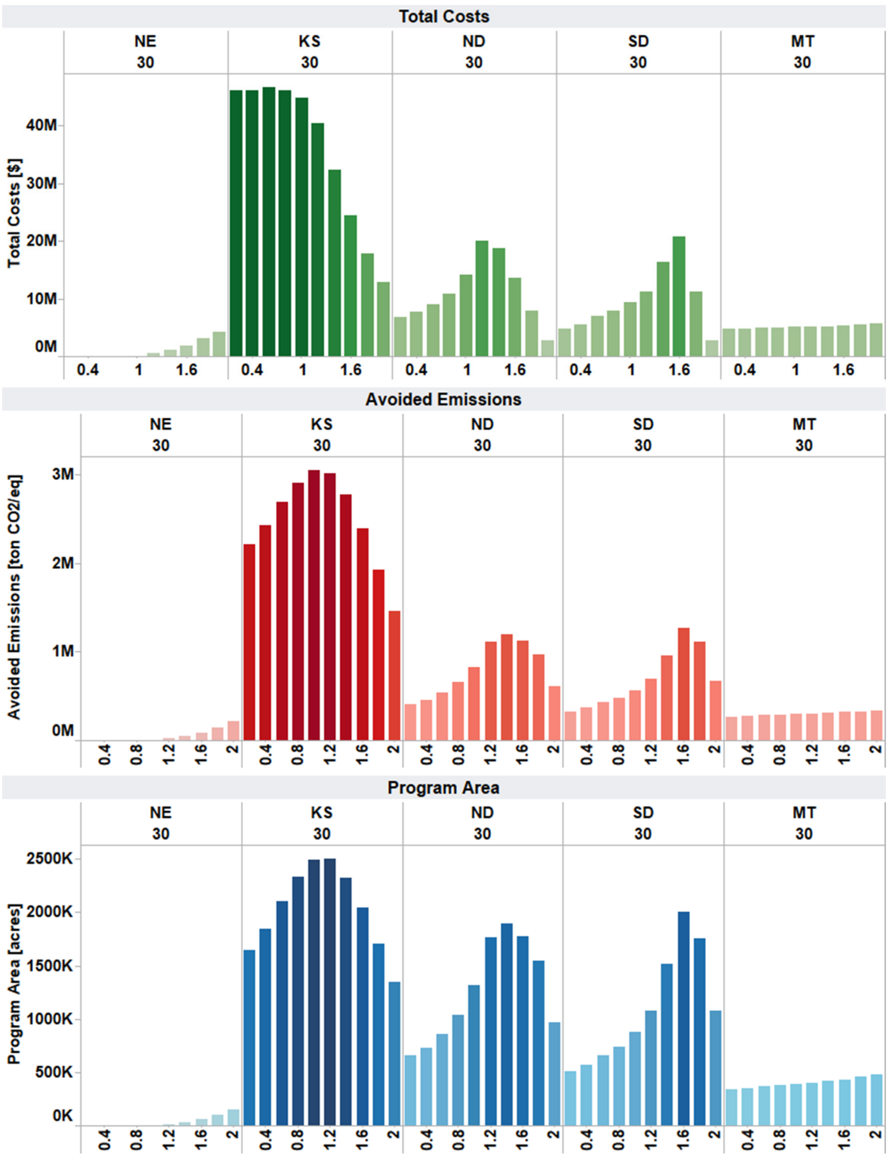

Figure 17: Total costs, avoided emissions, and program area by state at $40/tCO2e

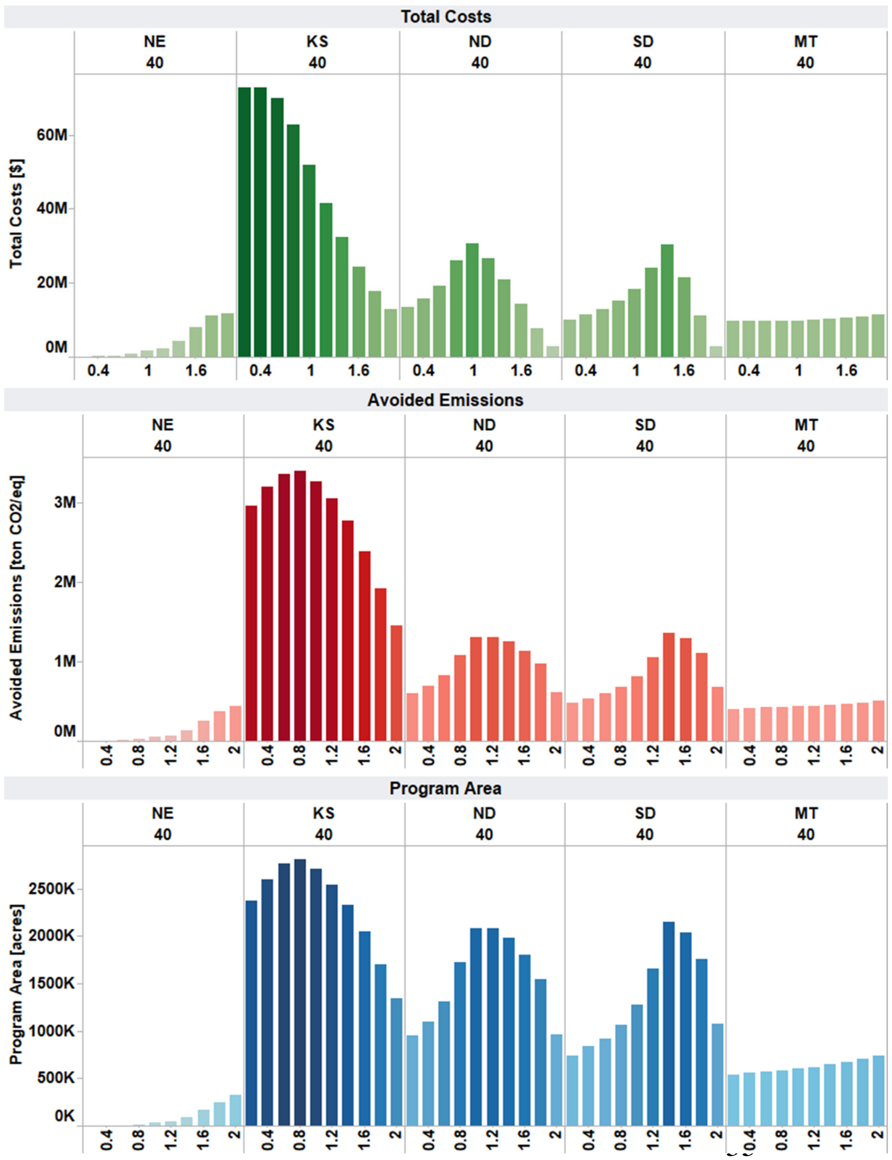

Figure 18: Average Abatement Costs for the PPR Region