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VERMONT GLOBAL WARMING SOLUTIONS ACT:
THE COSTS OF INACTION FROM LAND CONVERSIONS

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Plant and Environmental Sciences

by
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Accepted by:
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ABSTRACT

The Vermont (VT) Global Warming Solutions Act (GWSA, 2020) sets greenhouse gas (GHG) emissions reduction targets as 26% below 2005 by 2025, 40% below 1990 by 2030 and 80% below 1990 by 2050 for energy-related emissions only. Vermont's omission of GHG emissions from land conversions can result in significant costs of inaction (COI), which can hinder state's mitigation and adaptation plans and result in a climate crisis-related risks (e.g., credit downgrade). Science-based spatio-temporal data of GHG emissions from soils as a result of land conversions can be integrated into the conceptual framework of "action" versus "inaction" to prevent GHG emissions. The application of soil information data and remote sensing analysis can identify the GHG emissions from land conversions, which can be expressed as "realized" social costs of "inaction". This study demonstrates the rapid assessment of the value of regulating ecosystems services (ES) from soil organic carbon (SOC), soil inorganic carbon (SIC), and total soil carbon (TSC) stocks, based on the concept of the avoided social cost of carbon dioxide (CO₂) emissions for VT by soil order and county using remote sensing and information from the State Soil Geographic (STATSGO) and Soil Survey Geographic Database (SSURGO) databases. Classified land cover data for 2001 and 2016 were downloaded from the Multi-Resolution Land Characteristics Consortium (MRLC) website. These results provide accurate and quantitative spatio-temporal information about likely GHG emissions, which can be linked to VT's climate action plan. A failure to considerably reduce emissions from land conversions in the future may

need even larger reductions in the future and would increase climate change costs to VT and beyond its borders.

Keywords: carbon emissions; CO₂; climate change; damage; inorganic; law; organic; planning; risk

DEDICATION

I am dedicating this thesis to my family and friends who have motivated and inspired me to become a passionate, lifelong learner.

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CHAPTER ONE

VERMONT GLOBAL WARMING SOLUTIONS ACT: THE COSTS OF INACTION FROM LAND CONVERSIONS

Introduction

As John F. Kennedy once said: “*There are risks and costs to action. But they are far less than the long-range risks of comfortable inaction*” (Adler 2003). Assessing the costs of historical, current, and future inactions on climate change is important in climate change policy, which can be also incorporated into the economic and legal systems (Sanderson and O’Neill 2020). Traditionally, the concept of COI entails the future cost of climate change related disasters without mitigation and adaptation measures (European Environment Agency 2007). By estimating the partial COI of GHG emissions from land conversions, officials may find that inaction is more expensive than action to reduce climate change risks. Omission of GHG emissions from land conversions can result in significant COI, which can hinder Vermont’s mitigation and adaptation plans and result in a climate crisis-related consequences (e.g., credit downgrade). In order to quantify COI, it is important to estimate the social costs of emissions (e.g., SC-CO₂) that occur from land conversions in the absence of any regulatory policy. Since emissions can cause various environmental, economic, and societal consequences, a differentiation is frequently made between tangible, intangible, direct, and indirect damages (Nicklin et al. 2019).

1.1. The Role of Soils in the Vermont Global Warming Solutions Act (GWSA)

The state of VT seeks to achieve 80% below 1990 reduction in GHG emissions by 2050 (General Assembly of the State of Vermont 2020) for energy-related emissions only with specific initiatives outlined in the initial Climate Action Plan (Vermont Climate

Council 2021). Vermont is a participant in the U.S. Climate Alliance, a group of 25 states which have agreed to reduce GHG emissions in support of the Paris Agreement and United Nations Sustainable Development Goals (United Nations 2015; Keestra et al. 2016). The GWSA (2020) authorizes evaluating each GHG emission source or category of sources and identifying programs and strategies that could result in the most significant and cost-effective reductions of GHG emissions (General Assembly of the State of Vermont 2020). It also requires developing actions to increase carbon storage in forest and agricultural soils (General Assembly of the State of Vermont 2020). Despite identifying soils as a possible carbon sink, the current GSWA does not identify soil GHG emissions from land conversions, which could pose potential liability to Vermont's government for inadequate action in the face of climate change (Klein 2015).

Vermont's pedodiversity (state's soil type composition) determines the soil regulating ecosystem services/disservices (ES/ED) potential regarding its capacity to release or store CO₂ and the vulnerability to climate change (Table 1, Figure 1) (Mikhailova et al. 2021a). Vermont has six soil orders, which belong to slightly weathered (Entisols, Inceptisols, Histosols), moderately weathered (Alfisols, Mollisols), and strongly weathered (Spodosols) soils with various soil C storages and climate change vulnerabilities. The state of VT has selected Tunbridge as the State Soil (soil order: Spodosols) for its provisioning ES value (e.g., woodland, sugar maple) (Natural Resources Conservation Service n.d.).

Soils play an important role in VT's economy and can become a GHG emissions "hotspot" as a result of disturbance (e.g., natural, anthropogenic, etc.) (Figure 2). These emissions can be expressed as social costs, which can be "avoided" in case of action

(e.g., regulatory, conservation, prevention, etc.) or “realized” in case of inaction (e.g., damages). Since different soils have different carbon contents, these costs would vary by soil type and degree of disturbance. With a high proportion of private land ownership (84.2%, U.S. Bureau of the Census 1991) in the state, the costs of actions or inactions associated with GHG soil emissions can be tied directly to land ownership through existing public land ownership spatial databases and incorporated into VT’s strategic climate-related planning (Figure 2).

Although COI has been traditionally used to estimate the total potential costs of climate change, these estimates are often complex and subject to a large uncertainty. This study hypothesizes that the concept of COI can be used in a narrower context by estimating partial COI from specific sources, such as land conversions, which can be used by the state of VT to quantify and value GHG emissions using inexpensive remote sensing tools and publicly available data. Our study will use the current VT’s Act No. 153 “An Act Relating to Addressing Climate Change” (General Assembly of the State of Vermont 2020) and the initial Climate Action Plan (Vermont Climate Council 2021) to demonstrate how land cover and soil analyses can identify emission sources (e.g., CO₂ emissions hotspots linked to land cover change), which could be linked to either costs of action (“avoided” social costs; prevention) or costs of inaction (“realized” social costs; damages).

The objectives of this study were to assess the value of SOC, SIC, and TSC in VT (USA) and its change over 15 years using the social cost of C (SC–CO₂) and avoided emissions provided by C sequestration, which the U.S. Environmental Protection Agency (EPA) has determined to be \$46 per metric ton of CO₂, valid until 2025 based on 2007

U.S. dollars and an average discount rate of 3% (EPA 2016a). The provided calculations estimate the monetary values of SOC, SIC, and TSC in the state by different spatial aggregation levels (i.e., county) using the State Soil Geographic (STATSGO) and Soil Survey Geographic Database (SSURGO) databases and information reported by Guo et al. (2006). Classified land cover data (2001 and 2016) were obtained from the Multi-Resolution Land Characteristics Consortium (MRLC) website (MRLC n.d.).

2. Accounting for Soil Regulating Ecosystem Services in the State of Vermont

This study utilized biophysical (science-based, Figure 1) and administrative (boundary-based, Figure 1) accounts to estimate monetary values for SOC, SIC, and TSC (Tables 2 and 3). Although this framework was used primarily to account for soil regulating ES, it can be adapted to identify inaction costs. Table 2 was enhanced by the addition of an explanation of different interpretations of the social cost of carbon (SC-CO₂) emissions as “avoided“ through climate action or “realized“ through climate inaction.

The present study estimated monetary values associated with stocks of SOC, SIC, and TSC in VT based on reported contents (in kg m⁻²) from Guo et al. (2006). Values were calculated using the avoided social cost of carbon (SC-CO₂) of \$46 per metric ton of CO₂, applicable for 2025 based on 2007 U.S. dollars and an average discount rate of 3% (EPA 2016a). According to the EPA, the SC-CO₂ is intended to be a comprehensive estimate of climate change damages. Still, it can underestimate the true damages and cost of CO₂ emissions due to the exclusion of various important climate change impacts recognized in the literature (EPA 2016a). Area-normalized monetary values (\$ m⁻²) were

calculated using Equation (1), and total monetary values were summed over the appropriate area(s) (noting that a metric ton is equivalent to 1 megagram (Mg) or 1000 kilograms (kg), and SC = soil carbon, e.g., SOC, SIC, or TSC):

$$\frac{\$}{\text{m}^2} = \left(\text{SOC/SIC/TSC Content, } \frac{\text{kg}}{\text{m}^2} \right) \times \frac{1 \text{ Mg}}{10^3 \text{ kg}} \times \frac{44 \text{ Mg CO}_2}{12 \text{ Mg SC}} \times \frac{\$46}{\text{Mg CO}_2}$$

Table 4 presents area-normalized contents (kg m^{-2}) and monetary values ($\$ \text{m}^{-2}$) of soil carbon, which were used to estimate stocks of SOC, SIC, and TSC and their corresponding values by multiplying the contents/values by the area of a particular soil order within a county (Table 3). For example, for the soil order Inceptisols, Guo et al. (2006) reported a midpoint SOC content of 8.9 kg m^{-2} for the upper 2-m soil depth (Table 4). Using this SOC content in equation (1) results in an area-normalized SOC value of $\$1.50 \text{ m}^{-2}$. Multiplying the SOC content and its corresponding area-normalized value each by the total area of Inceptisols present in Vermont (8032 km^2 , Table 3) results in an estimated SOC stock of $7.1 \times 10^{10} \text{ kg}$ (Table 5) with an estimated monetary value of $\$12.0\text{B}$ (Table 6).

Land use/land cover change in VT between 2001 and 2016 was analyzed using classified land cover data from the MRLC (MRLC n.d.). Changes in land cover, with their associated soil types, were calculated in ArcGIS Pro 2.6 (ESRI n.d.) by comparing the 2001 and 2016 data, converting the land cover to vector format, and unioning the data with the soils layer in the Soil Survey Geographic (SSURGO) Database (Soil Survey Staff and September 2021).

3. Soil Carbon Regulating Ecosystem Services and Land Cover Change in the State of Vermont

Based on avoided SC–CO₂, the total estimated monetary mid-point value for TSC in the state of Vermont was \$65.3B (i.e., 65.3 billion U.S. dollars, where B = billion = 10⁹), \$53.5B for SOC (83% of the total value), and \$10.3B for SIC (17% of the total value). Previously, we have reported that among the 48 conterminous states of the U.S., Vermont ranked 41st for TSC (Mikhailova et al. 2019a), 41st for SOC (Mikhailova et al. 2019b), and 34th for SIC (Groshans et al. 2019).

3.1. Storage and Value of SOC by Soil Order and County for Vermont

Soil orders with the highest midpoint monetary value for SOC were Spodosols (\$24.2B), Histosols (\$14.2B), and Inceptisols (\$12.0B) (Tables 5 and 6). The counties with the highest midpoint SOC values were Orange (\$7.0B), Rutland (\$6.0B), and Addison (\$4.6B) (Tables 5 and 6).

3.2. Storage and Value of SIC by Soil Order and County for Vermont

Soil orders with the highest midpoint monetary value for SIC were: Inceptisols (\$6.9B), Spodosols (\$1.2B), and Entisols (\$757M, where M = million = 10⁶) (Tables 7 and 8). The counties with the highest midpoint SIC values were Windsor (\$1.4B), Rutland (\$1.3B), and Caledonia (\$1.1B) (Tables 7 and 8).

3.3. Storage and Value of TSC (SOC + SIC) by Soil Order and County for Vermont

Soil orders with the highest midpoint monetary value for TSC were Spodosols (\$27.0B), Inceptisols (\$19.0B), and Histosols (\$14.4B) (Tables 9 and 10). The counties with the highest midpoint TSC values were Orange (\$7.8B), Rutland (\$6.3B), and Windsor (\$6.1B) (Tables 9 and 10). These rankings are the same as for SOC and reflect the dominant contribution of SOC to TSC in the State.

3.4. Land Use/Land Cover Change by Soil Order in Vermont from 2001 to 2016

Vermont experienced changes in land use/land cover (LULC) over the 15-year period from 2001 to 2016 (Table 11, 12, 13, Figures 3, 4), resulting in soils emissions. Changes varied by soil order and original LULC classification, with most soil orders experiencing area losses in “low disturbance” LULC classes (e.g., evergreen forest, hay/pasture) while gaining in the areas of “developed” LULC classes. The largest increases in developed land areas occurred in Chittenden (\$16.2M), Bennington (\$8.3M), and Franklin (\$7.6M) counties. Chittenden is the most populous county in Vermont, and its county seat, the city of Burlington, is the most populous municipality in the state.

4. Significance of Results for Vermont’s Climate Policy

Vermont (VT) Global Warming Solutions Act (GWSA, 2020) sets greenhouse gas (GHG) emissions reduction targets for energy-related emissions only, but authorizes inventory of VT’s GHG emissions from other various sources (e.g., agriculture, forestry, etc.). These accomplishments are presented in the “Initial Vermont Climate Action Plan” from 2021, which is “organized around five areas: 1) emissions reductions; 2) building

resilience and adaptation in Vermont’s natural and working lands; 3) building resilience and adaptation in Vermont’s communities and built environment; 4) enhancing carbon sequestration and storage; and 5) cross-cutting pathways (those that are particularly impactful in supporting both the emissions reduction and resilience and adaptation efforts called for by the GWSA)” (Vermont Climate Council 2021). This plan approved the use of social cost of carbon for “the economic analysis of climate action plans and mitigation scenarios to account for the value of avoided emissions” (Vermont Climate Council 2021). Our study used this plan to demonstrate how soil and land cover analysis can identify and track emission sources (e.g., CO₂ emissions hotspots associated with land cover change) and understand how land cover change has and may impact GHG emissions.

Initial Vermont Climate Action Plan

The Vermont Greenhouse Gas Emissions Inventory and Forecast (1990-2017) (Department of Environmental Conservation 2021), states that it is challenging to quantify carbon fluxes from soils, land uses, land-use change, and forestry because of the complexity associated with land use and land-use change systems and components. Our study provides quantitative soil C inventory (Table 14) and its changes as a result of land conversions from 2001 to 2016 (reported in section 3.4). Table 14 presents the potential total COI that can occur in the absence of any regulations and/or investments in emissions-risk management in VT.

5. Significance of Results in Broader Context

Conversions of land from low intensity (e.g., pasture, forests, etc.) to high-intensity covers (e.g., developments) can result in considerable soil-based emissions, particularly if the soil is rich in soil organic matter (e.g., soil order of Histosols). Remote sensing can be used to assess the potential soil-based emissions using the conceptual framework of action versus inaction to prevent these emissions (Nkonya et al. 2011). In this case, the concept of “inaction” means the absence of regulatory interventions to prevent land cover conversions that release GHG emissions. The costs of inactions in limiting land conversions outweigh the costs of action because the effect of GHG emissions from land conversions has a global impact with long-term accumulating economic damages (Figure 5). According to Nkonya et al. (2011), “past assessments of land degradation have focused on the biophysical impacts rather than on the overall societal and economic costs and benefits of degradation prevention.”

Damages from land conversions can be variable with numerous economic, environmental, societal, and legal impacts (Figure 6). Figure 6 provides some of the examples of possible damages from soil emissions as a result of land conversions. Direct physical damages include carbon loss and increasing temperatures (Figure 6). State’s climate crisis-related credit downgrade is an example of indirect tangible damage as a result of insufficient strategies to address climate change (Figure 6).

Policymakers are increasingly facing a daunting task of budgeting for climate-change related expenses. The extent and intensity of climate change and its contributing factors varies by geographic location, therefore requiring a site-specific approach.

Determination of the COI is an important tool for achieving long-term GHG emission reductions. Although COI has been traditionally used as an attempt to estimate the total potential costs of climate change, these estimates are often complex and subject to a large uncertainty. Our study examined the potential of using the concept of COI in a narrower context by estimating partial COI from specific sources, such as land conversions, which can be used by the states to quantify and value GHG emissions using remote sensing tools and publicly available data. Figure 7 shows the value of TSC based on two possible scenarios: 1) the cost of action (avoided social cost) by sequestering carbon in the soil, 2) the cost of inaction (realized social cost) by releasing emissions to the atmosphere. Vermont's climate action plan can benefit from having a soil inventory with estimated maximum potential social costs of emissions if all soil carbon is released. Although the likelihood of complete soil carbon loss is low, this inventory represents the liability for inaction. Defining these potential emissions by soil order allows for targeted action (e.g., prevention of land conversion) since these soils vary in soil carbon content and vulnerability to carbon loss. The soil order of Histosols is often a subject of state and federal protection because it is found in wetlands and has high soil organic carbon content. This is an example where the "cost of action" is a regulatory action by the government to conserve wetlands which protects soil carbon from being lost into the atmosphere as a GHG.

6. Conclusions

This study examined the potential of using the concept of COI in a narrower context by estimating partial COI from specific sources, such as land conversions, which

can be used by the states to quantify and value GHG emissions using remote sensing tools and publicly available data. This study used analysis of soil and remote sensing-based land cover change to quantify the value and dynamics of soil C stocks at the state and county levels in VT. This analysis can be used for the scenario-based comparison of cost of action versus inaction with regards to soil-based emissions as a result of land conversions. The estimated total monetary mid-point value for TSC stocks in Vermont was \$65.3B (i.e., 65.3 billion U.S. dollars (USD), where B = billion = 10^9), \$53.5B for SOC stocks, and \$10.3B for SIC stocks. Soil orders with the highest midpoint value for SOC were Spodosols (\$24.2B), Histosols (\$14.2B), and Inceptisols (\$12.0B). Soil orders with the highest midpoint value for SIC were Inceptisols (\$6.9B), Spodosols (\$2.4B), and Entisols (\$757M) where M = million = 10^6). Soil orders with the highest midpoint value for TSC were Spodosols (\$27.0B), Inceptisols (\$19.0B), and Histosols (\$14.4B). The counties with the highest midpoint SOC values were Orange (\$7.0B), Rutland (\$6.0B), and Addison (\$4.6B). The counties with the highest midpoint SIC values were Windsor (\$1.4B), Rutland (\$1.3B), and Caledonia (\$1.1B). The counties with the highest midpoint TSC values were Orange (\$7.8B), Rutland (\$6.3B), and Windsor (\$6.1B). Land use/land cover (LULC) changes between 2001 and 2016 for VT had the maximum “realized” SC-CO₂ of \$64.0M with soil orders of Inceptisols (\$27.0M) and Spodosols (\$16.0M) contributing the largest share to the total value. Most “realized” SC-CO₂ were associated with so called “contagious” urban developments around already existing urbanized areas (e.g., Burlington, South Burlington, etc.). The counties that have exhibited the most development were Chittenden (\$16.2M), Bennington (\$8.3M), and Franklin (\$7.6M). Land cover change analysis integrated with soil cover can be a cost-effective method for

rapid assessment of soil carbon inventory and soil related GHG emissions on regular basis to monitor the compliance with the greenhouse gas (GHG) emissions reduction targets set by the state of Vermont. While this study focused on identifying realized social costs of C from past land conversions, these techniques could be applied to identify the COI from these emissions to potentially assign legal and financial responsibility.

CHAPTER TWO

OVERALL CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDY

Potential Improvements

Future related research to this study would be to use raster data for soil orders and land cover change that use the same scale so that one data set does not limit the accuracy of the other when the two are compared. In this study, the SSURGO soil data uses 10m cell sizes, but because the MRLC land cover maps use 30m cell size, the accuracy of our data is limited to the 30m scale. At the scale of a state, this margin of error will be relatively small compared to the total land area, but if one wanted to use the methods of this study for smaller areas, the margin of error increases with the smaller the area you analyze. If high-resolution land cover data was captured using UAVs, you could calculate the carbon loss on the parcel level with high relative accuracy. You would be limited to the 10m scale of the SSURGO data because more soil data will be more labor-intensive to acquire. The accuracy of the soil carbon data could be improved by intensive soil sampling at depth, however, this type of data collection is both labor and cost intensive, so it is nearly impossible to over large spatial scales.

Another possibility for this study would be the inclusion of carbon loss from trees harvesting for development. This could likely be accomplished using multi-temporal LiDAR data to measure the loss of tree biomass. Realistically this data could populate a study of its own due to the number of factors involved with accurately calculating the amount of carbon in the biomass that is removed and how much of that carbon is released as CO₂.

Overall Conclusions

This study estimated the social cost of carbon from land conversion in the state of Vermont. The use of the social cost of carbon and the ability to add a monetary value to the carbon that is released is beneficial as it contextualizes the data in a way that is more easily understood by a range of users. This monetary value can also be used as a baseline for fines used to discourage the development of soils that would produce CO₂ hotspots.

One limitation of this study is that it shows the social cost of carbon due to land development and other ecosystem services are not considered. Ideally, it would be possible to calculate the loss of value from multiple ecosystem services lost due to land development and find the social cost of other greenhouse gasses released due to soil disturbance. It would be challenging to calculate all of the different sources of potential ecosystem value and how much is lost due to high disturbance land development because of the lack of data for these areas.

APPENDICES

Appendix A

TABLES

Table 1. Soil diversity (pedodiversity) and ecosystem service types in Vermont (U.S.A.) (adapted from Mikhailova et al., 2021a).

Soil Order	Stocks	Ecosystem Services		
	General Characteristics and Constraints	Provisioning	Regulation/ Maintenance	Cultural
Slightly Weathered				
Entisols	Embryonic soils with ochric epipedon	x	x	x
Inceptisols	Young soils with ochric or umbric epipedon	x	x	x
Histosols	Organic soils with $\geq 20\%$ of organic carbon	x	x	x
Moderately Weathered				
Alfisols	Clay-enriched B horizon with B.S. $\geq 35\%$	x	x	x
Mollisols	Carbon-enriched soils with B.S. $\geq 50\%$	x	x	x
Strongly Weathered				
Spodosols	Coarse-textured soils with albic and spodic horizons	x	x	x

Note: B.S. = base saturation.

Table 2. An accounting framework used in this study (adapted from Groshans et al. (2019), which can also be used to determine the costs of action or inaction for climate mitigation policy.

OWNERSHIP (e.g., government, private, foreign, shared, single, etc.)					
Time (e.g., information disclosure, etc.)	STOCKS		FLOWS		VALUE
	Biophysical Accounts (Science-Based)	Administrative Accounts (Boundary-Based)	Monetary Account(s)	Benefit(s)	Total Value
	Soil extent:	Administrative extent:	Ecosystem good(s) and service(s):	Sector:	Types of value:
	Composite (total) stock: Total soil carbon (TSC) = Soil organic carbon (SOC) + Soil inorganic carbon (SIC)				
Past This study: 2001, 2016, Change (e.g., post-development disclosures)				Environment:	The social cost of carbon (SC-CO ₂) emissions can be interpreted as “avoided” through climate action or “realized” through climate inaction : - \$46 per metric ton of CO ₂ valid until 2025 (2007 U.S. dollars with an average discount rate of 3% (EPA 2016a))
Current (e.g., status)	- Soil orders (Entisols, Inceptisols, Histosols, Spodosols, Ultisols)	- State (Vermont) - County (14 counties)	- Regulating (e.g., carbon sequestration)	- Carbon sequestration	
Future (e.g., pre-development disclosures)					

Table 3. Soil diversity (pedodiversity) by county in Vermont (U.S.A.) based on Soil Survey Geographic (SSURGO) Database (Soil Survey Staff n.d.a.).

County	Total Area (km ²) (%)	Degree of Weathering and Soil Development					
		Slight			Moderate		Strong
		Entisols	Inceptisols	Histosols	Alfisols	Mollisols	Spodosols
		2016 Area (km ²), (% of Total County Area)					
Addison	1903 (8)	26.8 (1)	386.8 (20)	56.7 (3)	699.4 (37)	0.03 (0)	733.4 (39)
Bennington	1721 (7)	44.2 (3)	786.5 (46)	11.5 (1)	9.2 (1)	0	870.0 (51)
Caledonia	1674 (7)	22.1 (1)	1032.5 (62)	43.4 (3)	0	68.0 (4)	508.0 (30)
Chittenden	1334 (6)	97.8 (7)	270.6 (20)	21.8 (2)	89.4 (7)	39.8 (3)	814.8 (61)
Essex	1713 (7)	4.7 (0)	122.2 (7)	28.9 (2)	0	2.6 (0)	1554.6 (91)
Franklin	1630 (7)	205.8 (13)	473.7 (29)	5.8 (0)	24.6 (2)	10.1 (1)	909.8 (56)
Grand Isle	210 (1)	0	164.1 (78)	15.4 (7)	30.6 (15)	0	0
Lamoille	1099 (5)	8.6 (1)	334.6 (30)	7.2 (1)	0	0	749.2 (68)
Orange	1774 (8)	49.8 (3)	467.8 (26)	177.8 (10)	0	0.01 (0)	1078.3 (61)
Orleans	1754 (8)	40.1 (2)	524.4 (30)	64.9 (4)	0	149.3 (9)	975.5 (56)
Rutland	2151 (9)	108.7 (5)	1233.9 (57)	64.9 (3)	33.9 (2)	0	709.9 (33)
Washington	1715 (7)	78.5 (5)	468.8 (27)	18.6 (1)	0	0	1149.1 (67)
Windham	2010 (9)	136.1 (7)	367.6 (18)	60.9 (3)	0	10.5 (1)	1435.2 (71)
Windsor	2466 (11)	100.7 (4)	1398.5 (57)	22.7 (1)	0	5.9 (0)	937.9 (38)
Totals	23155 (100%)	924 (4)	8032 (35)	600 (3)	887 (4)	286 (1)	12426 (54)

Table 4. Area-normalized content (kg m^{-2}) and monetary values ($\text{\$ m}^{-2}$) of soil organic carbon (SOC), soil inorganic carbon (SIC), and total soil carbon (TSC) by soil order based on data reported by Guo et al. (2006) for the upper 2 m of soil and an avoided social cost of carbon (SC- CO_2) of \$46 per metric ton of CO_2 (2007 U.S. dollars with an average discount rate of 3% (EPA 2016a)).

Soil Order	SOC Content	SIC Content	TSC Content	SOC Value	SIC Value	TSC Value
	Minimum–Midpoint–Maximum Values			Midpoint Values		
	(kg m^{-2})	(kg m^{-2})	(kg m^{-2})	($\text{\$ m}^{-2}$)	($\text{\$ m}^{-2}$)	($\text{\$ m}^{-2}$)
Slightly Weathered						
Entisols	1.8–8.0–15.8	1.9–4.8–8.4	3.7–12.8–24.2	1.35	0.82	2.17
Inceptisols	2.8–8.9–17.4	2.5–5.1–8.4	5.3–14.0–25.8	1.50	0.86	2.36
Histosols	63.9–140.1–243.9	0.6–2.4–5.0	64.5–142.5–248.9	23.62	0.41	24.03
Moderately Weathered						
Alfisols	2.3–7.5–14.1	1.3–4.3–8.1	3.6–11.8–22.2	1.27	0.72	1.99
Mollisols	5.9–13.5–22.8	4.9–11.5–19.7	10.8–25.0–42.5	2.28	1.93	4.21
Strongly Weathered						
Spodosols	2.9–12.3–25.5	0.2–0.6–1.1	3.1–12.9–26.6	2.07	0.10	2.17

Note: TSC = SOC + SIC.

Table 5. Midpoint soil organic carbon (SOC) storage by soil order and county for the state of Vermont (USA), based on the areas shown in Table 3 and the midpoint SOC contents shown in Table 4.

County	Total Storage (kg) (%)	Degree of Weathering and Soil Development					
		Slight			Moderate		Strong
		Entisols	Inceptisols	Histosols	Alfisol	Mollisols	Spodosols
		Total SOC Storage (kg), (% of Total by County)					
Addison	2.6×10^{10} (8)	2.1×10^8 (1)	3.4×10^9 (13)	7.9×10^9 (31)	5.2×10^9 (20)	3.4×10^5 (0)	9.0×10^9 (35)
Bennington	2.0×10^{10} (6)	3.5×10^8 (2)	7.0×10^9 (35)	1.6×10^9 (8)	6.9×10^7 (0)	0	1.1×10^{10} (54)
Caledonia	2.3×10^{10} (7)	1.8×10^8 (1)	9.2×10^9 (41)	6.1×10^9 (27)	0	9.2×10^8 (4)	6.2×10^9 (28)
Chittenden	1.7×10^{10} (5)	7.8×10^8 (4)	2.4×10^9 (14)	3.1×10^9 (17)	6.7×10^8 (4)	5.4×10^8 (3)	1.0×10^{10} (57)
Essex	2.4×10^{10} (7)	3.7×10^7 (0)	1.1×10^9 (4)	4.1×10^9 (17)	0	3.4×10^7 (0)	1.9×10^{10} (79)
Franklin	1.8×10^{10} (6)	1.6×10^9 (9)	4.2×10^9 (23)	8.2×10^8 (5)	1.8×10^8 (1)	1.4×10^8 (1)	1.1×10^{10} (62)
Grand Isle	3.8×10^9 (1)	0	1.5×10^9 (38)	2.2×10^9 (56)	2.3×10^8 (6)	0	0
Lamoille	1.3×10^{10} (4)	6.9×10^7 (1)	3.0×10^9 (22)	1.0×10^9 (8)	0	0	9.2×10^9 (69)
Orange	4.3×10^{10} (13)	4.0×10^8 (1)	4.2×10^9 (10)	2.5×10^{10} (58)	0	6.8×10^4 (0)	1.3×10^{10} (31)
Orleans	2.8×10^{10} (9)	3.2×10^8 (1)	4.7×10^9 (17)	9.1×10^9 (32)	0	2.0×10^9 (7)	1.2×10^{10} (43)
Rutland	3.0×10^{10} (9)	8.7×10^8 (3)	1.1×10^{10} (37)	9.1×10^9 (30)	2.5×10^8 (1)	4.9×10^3 (0)	8.7×10^9 (29)
Washington	2.2×10^{10} (7)	6.3×10^8 (3)	4.2×10^9 (19)	2.6×10^9 (12)	0	0	1.4×10^{10} (66)
Windham	3.1×10^{10} (9)	1.1×10^9 (4)	3.3×10^9 (11)	8.5×10^9 (28)	0	1.4×10^8 (0)	1.8×10^{10} (58)
Windsor	2.8×10^{10} (9)	8.1×10^8 (3)	1.2×10^{10} (44)	3.2×10^9 (11)	0	7.9×10^7 (0)	1.2×10^{10} (41)
Totals	3.3×10^{11} (100)	7.4×10^9 (2)	7.1×10^{10} (22)	8.4×10^{10} (26)	6.7×10^9 (2)	3.9×10^9 (1)	1.5×10^{11} (47)

Table 6. Monetary value of soil organic carbon (SOC) by soil order and county for the state of Vermont (USA), based on the areas shown in Table 3 and the area-normalized midpoint monetary values shown in Table 4.

County	Total SC-CO ₂ (\$)	Degree of Weathering and Soil Development					
		Slight			Moderate		Strong
		Entisols	Inceptisols	Histosols	Alfisols	Mollisols	Spodosols
		SC-CO ₂ (\$ = USD)					
Addison	4.6×10^9	3.6×10^7	5.8×10^8	1.3×10^9	8.9×10^8	5.7×10^4	1.8×10^9
Bennington	2.6×10^9	6.0×10^7	1.2×10^9	2.7×10^8	1.2×10^7	0	1.1×10^9
Caledonia	4.4×10^9	3.0×10^7	1.5×10^9	1.0×10^9	0	1.5×10^8	1.7×10^9
Chittenden	4.5×10^9	1.3×10^8	4.1×10^8	5.1×10^8	1.1×10^8	9.1×10^7	3.2×10^9
Essex	2.8×10^9	6.3×10^6	1.8×10^8	6.8×10^8	0	5.8×10^6	1.9×10^9
Franklin	1.2×10^9	2.8×10^8	7.1×10^8	1.4×10^8	3.1×10^7	2.3×10^7	0
Grand Isle	2.2×10^9	0	2.5×10^8	3.6×10^8	3.9×10^7	0	1.6×10^9
Lamoille	2.9×10^9	1.2×10^7	5.0×10^8	1.7×10^8	0	0	2.2×10^9
Orange	7.0×10^9	6.7×10^7	7.0×10^8	4.2×10^9	0	1.1×10^4	2.0×10^9
Orleans	4.2×10^9	5.4×10^7	7.9×10^8	1.5×10^9	0	3.4×10^8	1.5×10^9
Rutland	6.0×10^9	1.5×10^8	1.9×10^9	1.5×10^9	4.3×10^7	8.2×10^2	2.4×10^9
Washington	4.2×10^9	1.1×10^8	7.0×10^8	4.4×10^8	0	0	3.0×10^9
Windham	4.1×10^9	1.8×10^8	5.5×10^8	1.4×10^9	0	2.4×10^7	1.9×10^9
Windsor	2.8×10^9	1.4×10^8	2.1×10^9	5.4×10^8	0	1.3×10^7	0
Totals	5.3×10^{10}	1.2×10^9	1.2×10^{10}	1.4×10^{10}	1.1×10^9	6.5×10^8	2.4×10^{10}

Table 7. Midpoint soil inorganic carbon (SIC) storage by soil order and county for the state of Vermont (USA), based on the areas shown in Table 3 and the midpoint SIC contents shown in Table 4.

County	Total Storage (kg) (%)	Degree of Weathering and Soil Development					
		Slight			Moderate		Strong
		Entisols	Inceptisols	Histosols	Alfisols	Mollisols	Spodosols
		Total SIC Storage (kg), (% of Total by County)					
Addison	5.7×10^9 (9)	1.3×10^8 (2)	2.0×10^9 (35)	1.4×10^8 (2)	3.0×10^9 (53)	2.9×10^5 (0)	4.4×10^8 (8)
Bennington	4.8×10^9 (8)	2.1×10^8 (4)	4.0×10^9 (83)	2.8×10^7 (1)	4.0×10^7 (1)	0	5.2×10^8 (11)
Caledonia	6.6×10^9 (11)	1.1×10^8 (2)	5.3×10^9 (80)	1.0×10^8 (2)	0	7.8×10^8 (12)	3.0×10^8 (5)
Chittenden	3.2×10^9 (5)	4.7×10^8 (15)	1.4×10^9 (43)	5.2×10^7 (2)	3.8×10^8 (12)	4.6×10^8 (14)	4.9×10^8 (15)
Essex	1.7×10^9 (3)	2.2×10^7 (1)	6.2×10^8 (37)	6.9×10^7 (4)	0	2.9×10^7 (2)	9.3×10^8 (56)
Franklin	4.2×10^9 (7)	9.9×10^8 (24)	2.4×10^9 (58)	1.4×10^7 (0)	1.1×10^8 (3)	1.2×10^8 (3)	5.5×10^8 (13)
Grand Isle	1.0×10^9 (2)	0	8.4×10^8 (83)	3.7×10^7 (4)	1.3×10^8 (13)	0	0
Lamoille	2.2×10^9 (4)	4.1×10^7 (2)	1.7×10^9 (77)	1.7×10^7 (1)	0	0	4.5×10^8 (20)
Orange	3.7×10^9 (6)	2.4×10^8 (6)	2.4×10^9 (65)	4.3×10^8 (12)	0	5.8×10^4 (0)	6.5×10^8 (17)
Orleans	5.3×10^9 (9)	1.9×10^8 (4)	2.7×10^9 (50)	1.6×10^8 (3)	0	1.7×10^9 (32)	5.9×10^8 (11)
Rutland	7.5×10^9 (12)	5.2×10^8 (7)	6.3×10^9 (83)	1.6×10^8 (2)	1.5×10^8 (2)	4.2×10^3 (0)	4.3×10^8 (6)
Washington	3.5×10^9 (6)	3.8×10^8 (11)	2.4×10^9 (68)	4.5×10^7 (1)	0	0	6.9×10^8 (20)
Windham	3.7×10^9 (6)	6.5×10^8 (18)	1.9×10^9 (51)	1.5×10^8 (4)	0	1.2×10^8 (3)	8.6×10^8 (24)
Windsor	8.3×10^9 (14)	4.8×10^8 (6)	7.1×10^9 (86)	5.4×10^7 (1)	0	6.8×10^7 (1)	5.6×10^8 (7)
Totals	6.1×10^{10} (100%)	4.4×10^9 (7)	4.1×10^{10} (67)	1.4×10^9 (2)	3.8×10^9 (6)	3.3×10^9 (5)	7.5×10^9 (12)

Table 8. Monetary value of soil inorganic carbon (SIC) by soil order and county for the state of Vermont (USA), based on the areas shown in Table 3 and the area-normalized midpoint monetary values shown in Table 4.

County	Total SC-CO ₂ (\$)	Degree of Weathering and Soil Development					
		Slight			Moderate		Strong
		Entisols	Inceptisols	Histosols	Alfisols	Mollisols	Spodosols
		SC-CO ₂ (\$ = USD)					
Addison	9.5×10^8	2.2×10^7	3.3×10^8	2.3×10^7	5.0×10^8	4.8×10^4	7.3×10^7
Bennington	8.1×10^8	3.6×10^7	6.8×10^8	4.7×10^6	6.7×10^6	0	8.7×10^7
Caledonia	1.1×10^9	1.8×10^7	8.9×10^8	1.8×10^7	0	1.3×10^8	5.1×10^7
Chittenden	5.4×10^8	8.0×10^7	2.3×10^8	8.9×10^6	6.4×10^7	7.7×10^7	8.1×10^7
Essex	2.8×10^8	3.8×10^6	1.1×10^8	1.2×10^7	0	4.9×10^6	1.6×10^8
Franklin	7.1×10^8	1.7×10^8	4.1×10^8	2.4×10^6	1.8×10^7	1.9×10^7	9.1×10^7
Grand Isle	1.7×10^8	0	1.4×10^8	6.3×10^6	2.2×10^7	0	0
Lamoille	3.7×10^8	7.0×10^6	2.9×10^8	2.9×10^6	0	0	7.5×10^7
Orange	6.2×10^8	4.1×10^7	4.0×10^8	7.3×10^7	0	9.7×10^3	1.1×10^8
Orleans	9.0×10^8	3.3×10^7	4.5×10^8	2.7×10^7	0	2.9×10^8	9.8×10^7
Rutland	1.3×10^9	8.9×10^7	1.1×10^9	2.7×10^7	2.4×10^7	7.0×10^2	7.1×10^7
Washington	5.9×10^8	6.4×10^7	4.0×10^8	7.6×10^6	0	0	1.1×10^8
Windham	6.2×10^8	1.1×10^8	3.2×10^8	2.5×10^7	0	2.0×10^7	1.4×10^8
Windsor	1.4×10^9	8.3×10^7	1.2×10^9	9.3×10^6	0	1.1×10^7	9.4×10^7
Totals	1.0×10^{10}	7.6×10^8	6.9×10^9	2.5×10^8	6.4×10^8	5.5×10^8	1.2×10^9

Table 9. Midpoint total soil carbon (TSC) storage by soil order and county for the state of Vermont (USA), based on the areas shown in Table 3 and the midpoint TSC contents shown in Table 4.

County	Total Storage (kg) (%)	Degree of Weathering and Soil Development					
		Slight			Moderate		Strong
		Entisols	Inceptisols	Histosols	Alfisols	Mollisols	Spodosols
		Total TSC Storage (kg), (% of Total by County)					
Addison	3.2×10^{10} (8)	3.4×10^8 (1)	5.4×10^9 (17)	8.1×10^9 (26)	8.3×10^9 (26)	6.3×10^5 (0)	9.5×10^9 (30)
Bennington	2.5×10^{10} (6)	5.7×10^8 (2)	1.1×10^{10} (45)	1.6×10^9 (7)	1.1×10^8 (0)	0	1.1×10^{10} (46)
Caledonia	2.9×10^{10} (8)	2.8×10^8 (1)	1.4×10^{10} (50)	6.2×10^9 (21)	0	1.7×10^9 (6)	6.6×10^9 (22)
Chittenden	2.1×10^{10} (5)	1.3×10^9 (6)	3.8×10^9 (18)	3.1×10^9 (15)	1.1×10^9 (5)	9.9×10^8 (5)	1.1×10^{10} (51)
Essex	2.6×10^{10} (7)	6.0×10^7 (0)	1.7×10^9 (7)	4.1×10^9 (16)	0	6.4×10^7 (0)	2.0×10^{10} (77)
Franklin	2.2×10^{10} (6)	2.6×10^9 (12)	6.6×10^9 (30)	8.3×10^8 (4)	2.9×10^8 (1)	2.5×10^8 (1)	1.2×10^{10} (52)
Grand Isle	4.9×10^9 (1)	0	2.3×10^9 (47)	2.2×10^9 (45)	3.6×10^8 (7)	0	0
Lamoille	1.5×10^{10} (4)	1.1×10^8 (1)	4.7×10^9 (30)	1.0×10^9 (7)	0	0	9.7×10^9 (62)
Orange	4.6×10^{10} (12)	6.4×10^8 (1)	6.5×10^9 (14)	2.5×10^{10} (55)	0	1.3×10^5 (0)	1.4×10^{10} (30)
Orleans	3.3×10^{10} (9)	5.1×10^8 (2)	7.3×10^9 (22)	9.3×10^9 (28)	0	3.7×10^9 (11)	1.3×10^{10} (38)
Rutland	3.7×10^{10} (10)	1.4×10^9 (4)	1.7×10^{10} (46)	9.3×10^9 (25)	4.0×10^8 (1)	9.0×10^3 (0)	9.2×10^9 (24)
Washington	2.5×10^{10} (6)	1.0×10^9 (4)	6.6×10^9 (26)	2.6×10^9 (11)	0	0	1.5×10^{10} (59)
Windham	3.4×10^{10} (9)	1.7×10^9 (5)	5.1×10^9 (15)	8.7×10^9 (25)	0	2.6×10^8 (1)	1.9×10^{10} (54)
Windsor	3.6×10^{10} (9)	1.3×10^9 (4)	2.0×10^{10} (54)	3.2×10^9 (9)	0	1.5×10^8 (0)	1.2×10^{10} (33)
Totals	3.9×10^{11} (100%)	1.2×10^{10} (3)	1.1×10^{11} (29)	8.6×10^{10} (22)	1.0×10^{10} (3)	7.2×10^9 (2)	1.6×10^{11} (41)

Table 10. Monetary value of total soil carbon (TSC) by soil order and county for the state of Vermont (USA), based on the areas shown in Table 3 and the area-normalized midpoint monetary values shown in Table 4.

County	Total SC-CO ₂ (\$)	Degree of Weathering and Soil Development					
		Slight			Moderate		Strong
		Entisols	Inceptisols	Histosols	Alfisols	Mollisols	Spodosols
SC-CO ₂ (\$ = USD)							
Addison	5.3×10^9	5.8×10^7	9.1×10^8	1.4×10^9	1.4×10^9	1.1×10^5	1.6×10^9
Bennington	4.1×10^9	9.6×10^7	1.9×10^9	2.8×10^8	1.8×10^7	0	1.9×10^9
Caledonia	4.9×10^9	4.8×10^7	2.4×10^9	1.0×10^9	0	2.9×10^8	1.1×10^9
Chittenden	3.5×10^9	2.1×10^8	6.4×10^8	5.2×10^8	1.8×10^8	1.7×10^8	1.8×10^9
Essex	4.4×10^9	1.0×10^7	2.9×10^8	7.0×10^8	0	1.1×10^7	3.4×10^9
Franklin	3.8×10^9	4.5×10^8	1.1×10^9	1.4×10^8	4.9×10^7	4.2×10^7	2.0×10^9
Grand Isle	8.2×10^8	0	3.9×10^8	3.7×10^8	6.1×10^7	0	0
Lamoille	2.6×10^9	1.9×10^7	7.9×10^8	1.7×10^8	0	0	1.6×10^9
Orange	7.8×10^9	1.1×10^8	1.1×10^9	4.3×10^9	0	2.1×10^4	2.3×10^9
Orleans	5.6×10^9	8.7×10^7	1.2×10^9	1.6×10^9	0	6.3×10^8	2.1×10^9
Rutland	6.3×10^9	2.4×10^8	2.9×10^9	1.6×10^9	6.7×10^7	1.5×10^3	1.5×10^9
Washington	4.2×10^9	1.7×10^8	1.1×10^9	4.5×10^8	0	0	2.5×10^9
Windham	5.8×10^9	3.0×10^8	8.7×10^8	1.5×10^9	0	4.4×10^7	3.1×10^9
Windsor	6.1×10^9	2.2×10^8	3.3×10^9	5.5×10^8	0	2.5×10^7	2.0×10^9
Totals	6.5×10^{10}	2.0×10^9	1.9×10^{10}	1.4×10^{10}	1.8×10^9	1.2×10^9	2.7×10^{10}

Table 11. Land use/land cover (LULC) change by soil order in Vermont (USA) from 2001 to 2016.

NLCD Land Cover Classes (LULC)	2016 Total Area by LULC (km ²) (Change in Area, 2001-2006, %)	Degree of Weathering and Soil Development					
		Slight			Moderate		Strong
		Entisols	Inceptisols	Histosols	Alfisols	Mollisols	Spodosols
2016 Area by Soil Order, km ² (Change in Area, 2001–2016, %)							
Barren land	30 (-1.1%)	6.01 (-1.1%)	10.6 (1.9%)	1.0 (-38.2%)	1.5 (-1.9%)	0.2 (2.9%)	11.1 (-1.6%)
Woody wetlands	1036 (-0.9%)	93.4 (-0.9%)	416.1 (-1.4%)	240.2 (-0.7%)	46.9 (-2.7%)	7.3 (0.9%)	232.0 (-0.3%)
Shrub/Scrub	281 (130.8%)	5.0 (130.8%)	73.3 (193.1%)	2.0 (228.3%)	1.2 (-3.7%)	3.6 (219.2%)	195.5 (190.8%)
Mixed forest	5156 (-0.5%)	101.9 (-0.5%)	1540.4 (-0.5%)	103.4 (0.0%)	31.9 (4.2%)	70.1 (-0.1%)	3308.3 (-0.4%)
Deciduous forest	8701 (-2.7%)	144.7 (-2.7%)	2591.1 (-2.9%)	57.6 (-1.0%)	73.2 (-11.3%)	104.3 (-1.6%)	5729.9(-2.0%)
Herbaceous	223 (203.9%)	7.2 (203.9%)	101.7 (220.0%)	2.5 (91.5%)	8.0 (540.3%)	2.8 (58.4%)	100.4 (65.4%)
Evergreen forest	3045 (-2.1%)	137.4 (-2.1%)	1148.1 (-2.1%)	91.0 (-1.7%)	34.7 (-0.6%)	48.5 (-2.1%)	1584.3 (-1.7%)
Emergent herbaceous wetlands	172 (2.3%)	26.7 (2.3%)	61.2 (13.3%)	45.3 (10.5%)	22.3 (3.8%)	0.7 (-8.0%)	15.9 (12.9%)
Hay/Pasture	2702 (-3.3%)	187.3 (-3.3%)	1305.9 (-3.2%)	31.0 (-2.5%)	484.6 (-9.2%)	30.9 (-4.2%)	662.76 (-3.2%)
Cultivated crops	413 (6.5%)	63.4 (6.5 %)	180.9 (15.2%)	2.6 (6.1%)	121.0 (68.6%)	3.4 (5.4%)	41.5 (16.0%)
Developed, open space	814 (-0.7%)	54.4 (-0.7%)	344.6 (0.5%)	16.9 (0.3%)	26.9 (1.8%)	9.2 (1.7%)	361.9 (0.4%)
Developed, medium intensity	162 (6.4%)	34.1 (6.4%)	70.5 (7.7%)	1.3 (10.4%)	9.9 (8.5%)	1.0 (12.0%)	44.8 (6.9%)
Developed, low intensity	385 (0.8%)	53.3 (0.8%)	172.9 (1.6%)	5.6 (1.6%)	23.1 (3.4%)	3.7 (2.5%)	126.8 (1.4%)
Developed, high intensity	36 (10.1%)	9.2 (10.1%)	13.8 (14.1%)	0.2 (19.2%)	1.9 (18.0%)	0.2 (64.6%)	10.6 (10.9%)

Table 12. Increases in developed land and maximum potential for realized social costs of carbon due to complete loss of total soil carbon of developed land by soil order in Vermont (USA) from 2001 to 2016. Values are derived from Tables 4 and 11.







NLCD Land Cover Classes (LULC)	Degree of Weathering and Soil Development					
	Slight			Moderate		Strong
	Entisols	Inceptisols	Histosols	Alfisols	Mollisols	Spodosols
	Area Change, km ² (SC-CO ₂ , \$ = USD)					
Developed, open space	-	1.5 (\$3.6M)	-	0.5 (\$0.9M)	0.2 (\$0.7M)	1.4 (\$3.0M)
Developed, medium intensity	2.1 (\$4.5M)	5.0 (\$11.9M)	0.1 (\$3.0M)	0.8 (\$1.5M)	0.1 (\$0.4M)	2.9(\$6.3M)
Developed, low intensity	0.4 (\$0.9M)	2.7 (\$6.4M)	0.1 (\$2.1M)	0.8 (\$1.5M)	0.1 (\$0.4M)	1.8 (\$3.9M)
Developed, high intensity	0.8 (\$1.8M)	1.7 (\$4.0M)	-	0.3 (\$0.6M)	0.1 (\$0.4M)	1.0 (\$2.2M)
Totals (\$61.8M)	3.0 (\$7.2M)	11.0 (\$25.9M)	0.3 (\$6.9M)	2.3 (\$4.5M)	0.4 (\$1.9M)	7.1 (\$15.4M)

Note: Entisols, Inceptisols, Mollisols, and Spodosols are mineral soils. Histosols are mostly organic soils.
M = million = 10⁶.

Table 13. Increases in land development (LULC: developed open space, developed medium intensity, developed low intensity, and developed high intensity) and maximum potential for realized social costs of C due to complete loss of total soil carbon of developed land by soil order and county in Vermont (USA) from 2001 to 2016.

County	Total Area Change (km ²) (SC-CO ₂ , \$ = USD)	Degree of Weathering and Soil Development					
		Slight			Moderate		Strong
		Entisols	Inceptisols	Histosols	Alfisols	Mollisols	Spodosols
		Developed Area Increase between 2001 and 2016 (km ²)					
Addison	1.34 (\$2.8M)	0	0.21	0	1.04	0	0.09
Bennington	3.59 (\$8.3M)	0.24	2.83	0	0.03	0	0.49
Caledonia	0.60 (\$2.1M)	0.10	0.23	0.03	0	0.04	0.20
Chittenden	6.69 (\$16.2M)	0.77	2.68	0.06	1.11	0.05	2.01
Essex	0.07 (\$179,300)	0	0.03	0	0	0	0.05
Franklin	3.30 (\$7.6M)	0.77	2.11	0	0.07	0	0.36
Grand Isle	0.19 (\$437,300)	0	0.16	0	0.03	0	0
Lamoille	0.65 (\$1.4M)	0.01	0.14	0	0	0	0.50
Orange	0.30 (\$1.1M)	0.07	0.13	0.02	0	0	0.08
Orleans	1.09 (\$3.7M)	0.06	0.27	0.04	0	0.21	0.51
Rutland	2.35 (\$6.0M)	0.89	1.09	0.03	0.01	0	0.33
Washington	1.19 (\$2.9M)	0.04	0.50	0.01	0	0	0.64
Windham	1.97 (\$5.6M)	0.25	0.20	0.05	0	0.12	1.34
Windsor	1.98 (\$5.8M)	0.40	0.78	0.06	0	0.03	0.71
Totals	25.31 (\$64.1M)	3.60	11.36	0.30	2.29	0.45	7.31

Table 14. Distribution of soil carbon regulating ecosystem services in the state of Vermont (USA) by soil order (photos courtesy of USDA/NRCS (Soil Survey Staff n.d.b.). Values are taken/derived from Tables 3, 6, 8, and 10.

Soil Regulating Ecosystem Services in the State of Vermont					
Degree of Weathering and Soil Development					
Slight 41%			Moderate 5%		Strong 54%
Entisols 4%	Inceptisols 35%	Histosols 2%	Alfisols 4%	Mollisols 1%	Spodosols 54%
					
Social cost of soil organic carbon (SOC): \$53.5B					
\$1.2B	\$12.0B	\$14.2B	\$1.1B	\$652.1M	\$24.2B
2%	23%	27%	2%	1%	45%
Social cost of soil inorganic carbon (SIC): \$10.3B					
\$757.5M	\$6.9B	\$246.2M	\$638.7M	\$552.0M	\$2.4B
7.3%	66.8%	2%	6%	5%	12%
Social cost of total soil carbon (TSC): \$65.3B					
\$2.0B	\$19.0B	\$14.4B	\$1.8B	\$1.2B	\$27.0B
3%	29%	22%	3%	2%	41%
Sensitivity to climate change					
Low	Low	High	High		Low
SOC and SIC sequestration (recarbonization) potential					
Low	Low	Low	Low	Low	Low

Note: Entisols, Inceptisols, Mollisols, and Spodosols are mineral soils. Histosols are mostly organic soils. M = million = 10⁶; B = billion = 10⁹.

Appendix B

FIGURES

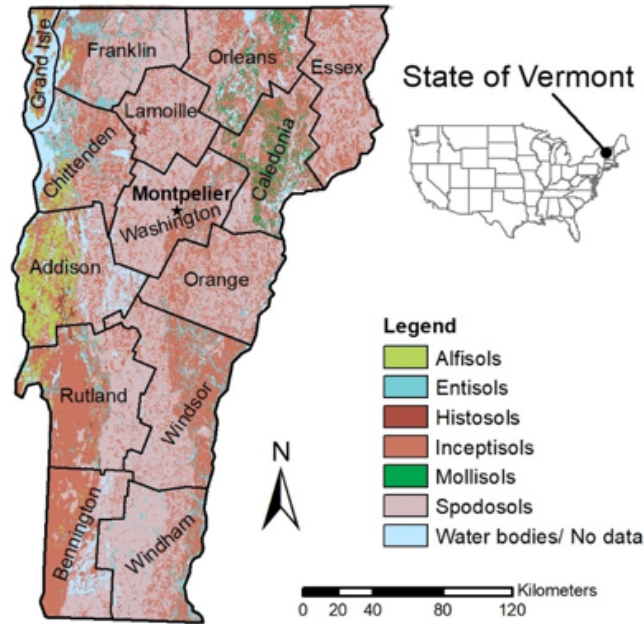


Figure 1. Soil map of Vermont (U.S.A.) (Latitude: 42°44' N to 45°1' N; Longitude: 71°28' W to 73°26' W) derived from the SSURGO database (Soil Survey Staff, September 2021) overlaid with county boundaries (The United States Census Bureau, 2018).

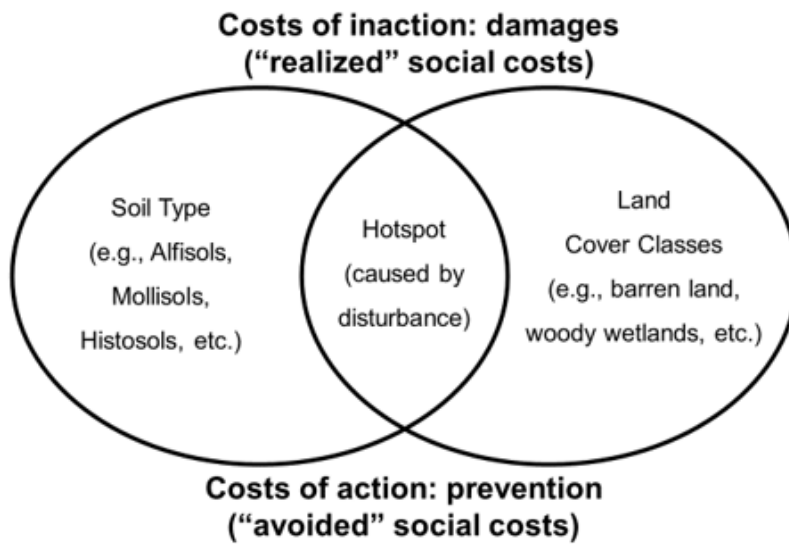


Figure 2. The soil “hotspot” caused by anthropogenic or natural disturbances (adapted from Bétard and Peulvast 2019; Mikhailova et al. 2021b), which can result in social costs. These social costs can be interpreted using the concept of costs of inaction (COI).

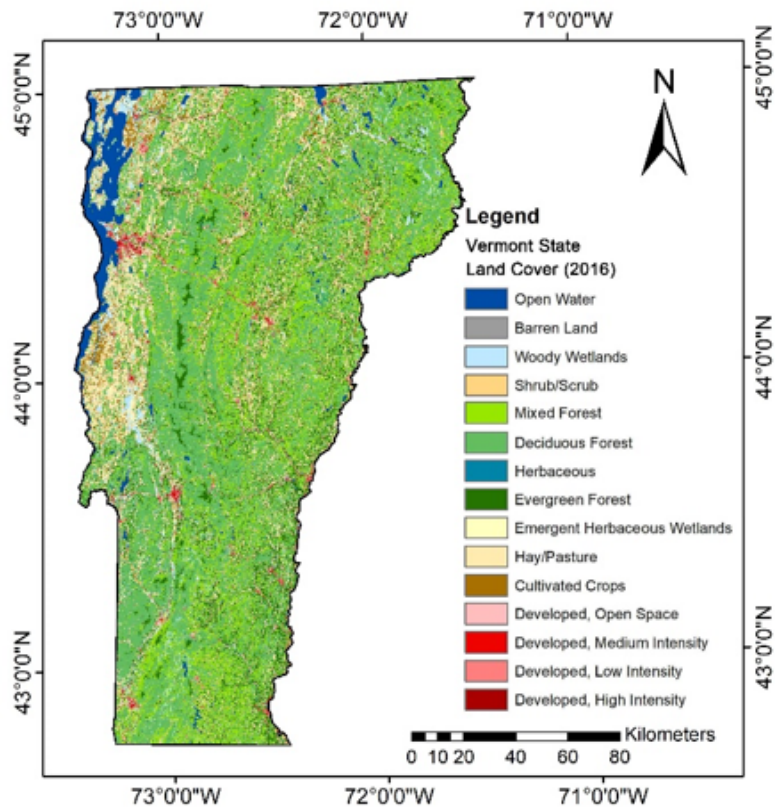


Figure 3. Land cover map of Vermont (U.S.A.): 2016 (Latitude: 42° 44' N to 45° 1' N; Longitude: 71° 28' W to 73° 26' W) (based on data from (MRLC n.d.)).

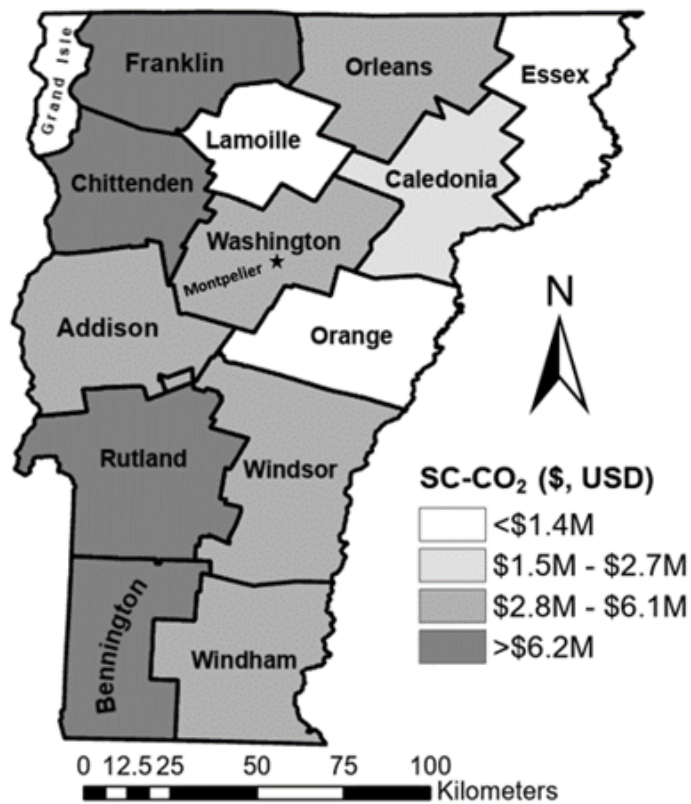


Figure 4. The total dollar value of mid-point total soil carbon (TSC) storage value for newly "de-developed" land covers (open space, low, medium, and high intensity) from 2001 to 2016 in Vermont (U.S.A.) based on a social cost of C (SC-CO₂) of \$46 per metric ton of CO₂ applicable for the year 2025 (2007 U.S. dollars with an average discount rate of 3% (EPA 2016a)).

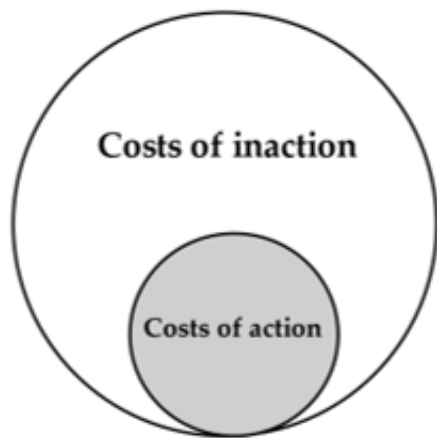


Figure 5. Interrelationship between costs of inaction and costs of action.

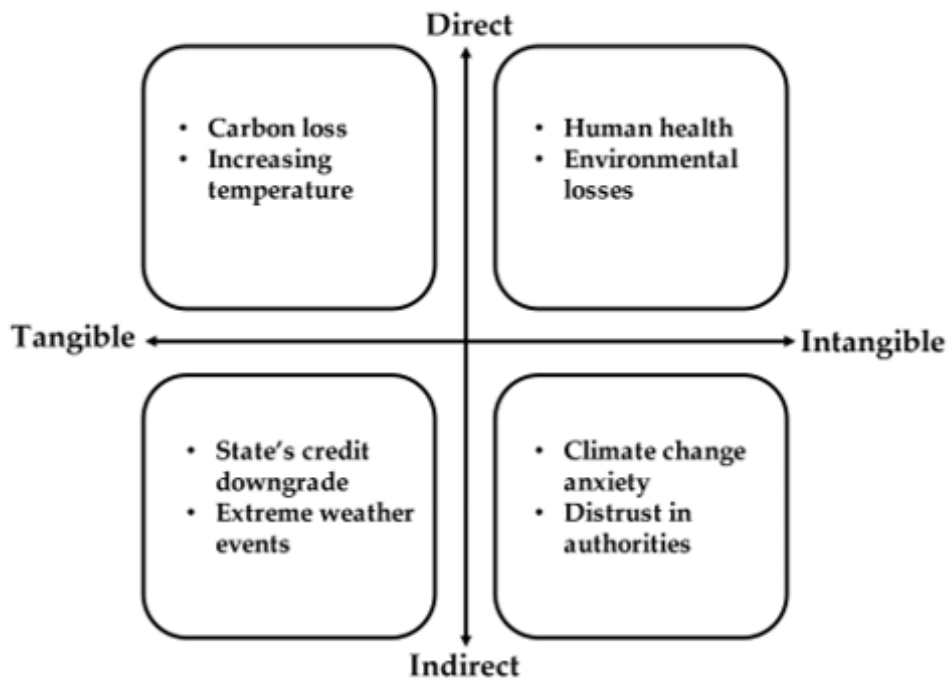


Figure 6. Examples of tangible, intangible, direct, and indirect emission damages, which can include emissions from land conversions (adapted from Nicklin et al. 2019).

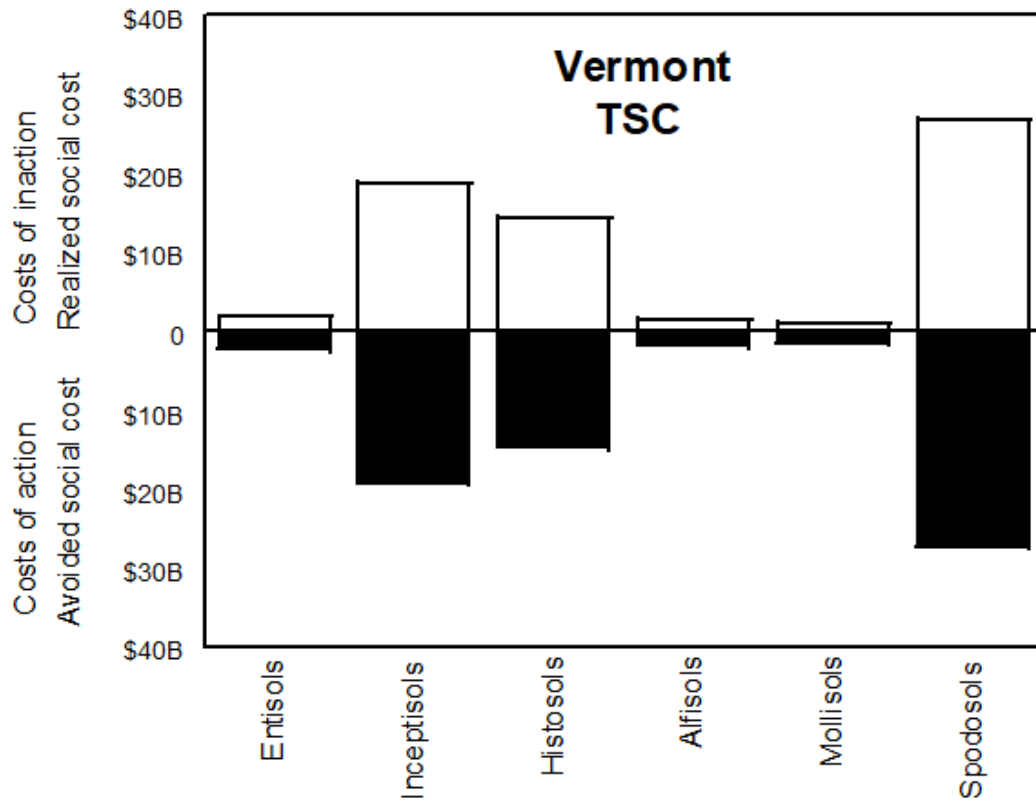


Figure 7. Comparison of costs of action (avoided social costs) with costs of inaction (realized social costs) using the monetary value of total soil carbon (TSC) storage or potential cost if all TSC is released as CO₂ emissions. Monetary valuation is based on soil C in the upper 2-m depth and a social cost of CO₂ emission of \$46 (USD) per metric ton of CO₂ applicable for the year 2025 (2007 U.S. dollars with an average discount rate of 3% (EPA 2016a)). Note: B = billion = 10⁹.

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