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Vermont Global Warming Solutions Act: The Costs of Inaction from Land Conversions

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Abstract: The Vermont (VT) Global Warming Solutions Act (GWSA, 2020) sets greenhouse gas (GHG) emissions reduction targets at 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 could result in significant costs of inaction (COI), which could hinder the state's mitigation and adaptation plans and result in climate crisis-related risks (e.g., credit downgrade). Science-based spatio-temporal data of GHG emissions from soils because 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 (CO_2) 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 would increase climate change costs and potential legal consequences for VT and beyond its borders.

Keywords: carbon; emissions; CO_2; climate change; damage; inorganic; law; organic; planning; risk

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1. 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 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 VT's mitigation and adaptation plans and result in climate crisis-related consequences (e.g., credit downgrade, increase in vulnerability to lawsuits). In order to quantify COI, it is important to estimate the social costs of emissions (e.g., SC-CO_2) 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).

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

The state of VT seeks to achieve 80% reduction below the 1990 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 in 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 a potential liability to VT's government for inadequate action in the face of climate change (Klein 2015).

Vermont's pedodiversity (the state's soil composition) determines the soil regulating ecosystem services/disservices (ES/ED) potential regarding its capacity to release or store CO_2 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.).

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

Stocks		**Ecosystem Services**		
Soil Order	**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 ≥20% of organic carbon	x	x	x
	Moderately Weathered			
Alfisols	Clay-enriched B horizon with B.S. ≥35%	x	x	x
Mollisols	Carbon-enriched soils with B.S. ≥50%	x	x	x
	Strongly Weathered			
Spodosols	Coarse-textured soils with albic and spodic horizons	x	x	x

Note: B.S. = base saturation.

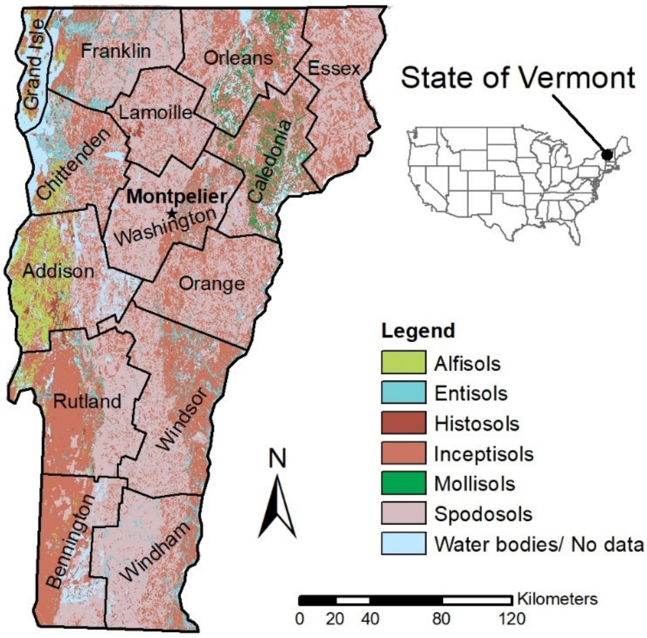


Figure 1. Soil map of Vermont (U.S.A.) (Latitude: 42°44′ N to 45°1′ N; Longitude: 71°28′ W to 73°26′ W) derived from the SSURGO database (Soil Survey Staff n.d.a) overlaid with county boundaries (The United States Census Bureau 2018).

Soils play an important role in VT's economy and can become a GHG emissions "hotspot" because 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).

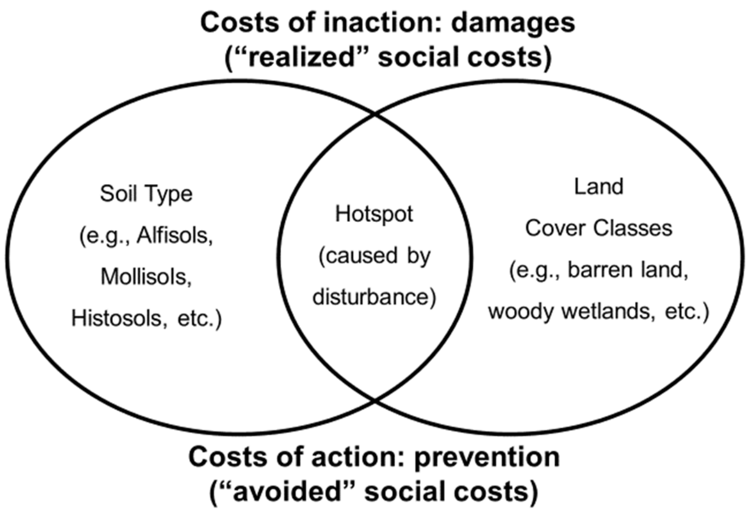


Figure 2. The soil "hotspot" is caused by anthropogenic or natural disturbances (adapted from Bétard and Peulvast 2019; Mikhailova et al. 2021b), which can result in social costs. These social costs can be interpreted using the concept of costs of inaction (COI).

Although COI has been traditionally used to estimate the total potential costs of climate change, these estimates are often complex and subject to 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., CO_2 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–CO_2) and avoided emissions provided by C sequestration, which the U.S. Environmental Protection Agency (EPA) has determined to be $46 (where $ = USD) per metric ton of CO_2, valid until 2025 based on 2007 U.S. dollars and an average discount rate of 3% (EPA—United States Environmental Protection Agency 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 (Multi-Resolution Land Characteristics Consortium—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-CO_2) emissions as "avoided" through climate action or "realized" through climate inaction.

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.)					
	STOCKS		**FLOWS**		**VALUE**
Time (e.g., information disclosure, etc.)	**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 (e.g., post-development disclosures) **Current** (e.g., status) **Future** (e.g., pre-development disclosures)	- Soil orders (Entisols, Inceptisols, Histosols, Spodosols, Ultisols)	- State (Vermont) - County (14 counties)	- Regulating (e.g., carbon sequestration)	Environment: - Carbon sequestration	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—United States Environmental Protection Agency 2016a))

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	1903.1 (8)	26.8 (1)	386.8 (20)	56.7 (3)	699.4 (37)	0.03 (0)	733.4 (39)
Bennington	1721.5 (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	1334.1 (6)	97.8 (7)	270.6 (20)	21.8 (2)	89.4 (7)	39.8 (3)	814.8 (61)
Essex	1712.9 (7)	4.7 (0)	122.2 (7)	28.9 (2)	0	2.6 (0)	1554.6 (91)
Franklin	1629.8 (7)	205.8 (13)	473.7 (29)	5.8 (0)	24.6 (2)	10.1 (1)	909.8 (56)
Grand Isle	210.0 (1)	0	164.1 (78)	15.4 (7)	30.6 (15)	0	0
Lamoille	1099.5 (5)	8.6 (1)	334.6 (30)	7.2 (1)	0	0	749.2 (68)
Orange	1773.7 (8)	49.8 (3)	467.8 (26)	177.8 (10)	0	0.01 (0)	1078.3 (61)
Orleans	1754.2 (8)	40.1 (2)	524.4 (30)	64.9 (4)	0	149.3 (9)	975.5 (56)
Rutland	2151.5 (9)	108.7 (5)	1233.9 (57)	64.9 (3)	33.9 (2)	0	709.9 (33)
Washington	1715.0 (7)	78.5 (5)	468.8 (27)	18.6 (1)	0	0	1149.1 (67)
Windham	2010.3 (9)	136.1 (7)	367.6 (18)	60.9 (3)	0	10.5 (1)	1435.2 (71)
Windsor	2465.6 (11)	100.7 (4)	1398.5 (57)	22.7 (1)	0	5.9 (0)	937.9 (38)
Totals	**23155.2 (100)**	**923.8 (4)**	**8032.0 (34)**	**600.5 (3)**	**887.1 (4)**	**286.0 (1)**	**12425.7 (54)**

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-CO_2) of $46 per metric ton of CO_2, applicable for 2025 based on 2007 U.S. dollars and an average discount rate of 3% (EPA—United States Environmental Protection Agency 2016a). According to the EPA, the SC-CO_2 is intended to be a comprehensive estimate of climate change damages. Still, it can underestimate the true damages and cost of CO_2 emissions due to the exclusion of various important climate-change impacts recognized in the literature (EPA—United States Environmental Protection Agency 2016a). Area-normalized monetary values ($ m^{-2}) were calculated using Equation (1), and the 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):

$$\frac{\$}{m^2} = \left(\text{SOC/SIC/TSC Content}, \frac{kg}{m^2}\right) \times \frac{1\ Mg}{10^3\ kg} \times \frac{44\ Mg\ CO_2}{12\ Mg\ SC} \times \frac{\$46}{Mg\ CO_2} \quad (1)$$

Table 4 presents area-normalized contents (kg m^{-2}) and monetary values ($ 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 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 7.1×10^{10} kg (Table 5) with an estimated monetary value of $12.0B.

Land use/land cover change in VT between 2001 and 2016 was analyzed using classified land cover data from the MRLC (Multi-Resolution Land Characteristics Consortium—MRLC n.d.). Changes in land cover, with their associated soil types, were calculated in ArcGIS Pro 2.6 (ESRI—Environmental Systems Research Institute n.d.) by comparing the 2001 and 2016 data, converting the land cover to vector format, and unioning the data with the soil layer in the Soil Survey Geographic (SSURGO) Database (Soil Survey Staff n.d.a).

Table 4. Area-normalized content (kg m^{-2}) and monetary values ($ m^{-2}) of soil organic carbon (SOC), soil inorganic carbon (SIC), and total soil carbon (TSC = SOC + SIC) 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 valid until 2025 (2007 U.S. dollars with an average discount rate of 3% (EPA—United States Environmental Protection Agency 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})	($ m^{-2})	($ m^{-2})	($ 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

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 SOC Storage (kg) (%)	Degree of Weathering and Soil Development					
		Slight			Moderate		Strong
		Entisols	Inceptisols	Histosols	Alfisols	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)**

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

Based on avoided SC–CO_2, the total estimated monetary mid-point value for TSC in the state of VT was $65.3B (i.e., 65.3 billion U.S. dollars, where B = billion = 10^9), $55.0B for SOC (84% of the total value), and $10.3B for SIC (16% of the total value). Previously, we have reported that among the 48 conterminous states of the U.S., VT 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 ($25.7B), Histosols ($14.2B), and Inceptisols ($12.0B) (Tables 5 and 6). The counties with the highest midpoint SOC values were Orange ($7.2B), Windham ($5.2B), and Rutland ($5.0B) (Tables 5 and 6).

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 ($ = USD)	Degree of Weathering and Soil Development					
		Slight			Moderate		Strong
		Entisols	Inceptisols	Histosols	Alfisols	Mollisols	Spodosols
		SC-CO_2 ($ = USD)					
Addison	4.4×10^9	3.6×10^7	5.8×10^8	1.3×10^9	8.9×10^8	5.7×10^4	1.5×10^9
Bennington	3.3×10^9	6.0×10^7	1.2×10^9	2.7×10^8	1.2×10^7	0	1.8×10^9
Caledonia	3.8×10^9	3.0×10^7	1.5×10^9	1.0×10^9	0	1.5×10^8	1.1×10^9
Chittenden	2.9×10^9	1.3×10^8	4.1×10^8	5.1×10^8	1.1×10^8	9.1×10^7	1.7×10^9
Essex	4.1×10^9	6.3×10^6	1.8×10^8	6.8×10^8	0	5.8×10^6	3.2×10^9
Franklin	3.1×10^9	2.8×10^8	7.1×10^8	1.4×10^8	3.1×10^7	2.3×10^7	1.9×10^9
Grand Isle	6.5×10^8	0	2.5×10^8	3.6×10^8	3.9×10^7	0	0
Lamoille	2.2×10^9	1.2×10^7	5.0×10^8	1.7×10^8	0	0	1.6×10^9
Orange	7.2×10^9	6.7×10^7	7.0×10^8	4.2×10^9	0	1.1×10^4	2.2×10^9
Orleans	4.7×10^9	5.4×10^7	7.9×10^8	1.5×10^9	0	3.4×10^8	2.0×10^9
Rutland	5.0×10^9	1.5×10^8	1.9×10^9	1.5×10^9	4.3×10^7	8.2×10^2	1.5×10^9
Washington	3.6×10^9	1.1×10^8	7.0×10^8	4.4×10^8	0	0	2.4×10^9
Windham	5.2×10^9	1.8×10^8	5.5×10^8	1.4×10^9	0	2.4×10^7	3.0×10^9
Windsor	4.7×10^9	1.4×10^8	2.1×10^9	5.4×10^8	0	1.3×10^7	1.9×10^9
Totals	$\mathbf{5.5 \times 10^{10}}$	$\mathbf{1.2 \times 10^9}$	$\mathbf{1.2 \times 10^{10}}$	$\mathbf{1.4 \times 10^{10}}$	$\mathbf{1.1 \times 10^9}$	$\mathbf{6.5 \times 10^8}$	$\mathbf{2.6 \times 10^{10}}$

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 = 10^6) (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).

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 SIC 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	$\mathbf{6.1 \times 10^{10}}$ **(100)**	$\mathbf{4.4 \times 10^9}$ **(7)**	$\mathbf{4.1 \times 10^{10}}$ **(67)**	$\mathbf{1.4 \times 10^9}$ **(2)**	$\mathbf{3.8 \times 10^9}$ **(6)**	$\mathbf{3.3 \times 10^9}$ **(5)**	$\mathbf{7.5 \times 10^9}$ **(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 ($ = USD)	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	$\mathbf{1.0 \times 10^{10}}$	$\mathbf{7.6 \times 10^8}$	$\mathbf{6.9 \times 10^9}$	$\mathbf{2.5 \times 10^8}$	$\mathbf{6.4 \times 10^8}$	$\mathbf{5.5 \times 10^8}$	$\mathbf{1.2 \times 10^9}$

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.

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 TSC 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	$\mathbf{3.9 \times 10^{11}}$ **(100)**	$\mathbf{1.2 \times 10^{10}}$ **(3)**	$\mathbf{1.1 \times 10^{11}}$ **(29)**	$\mathbf{8.6 \times 10^{10}}$ **(22)**	$\mathbf{1.0 \times 10^{10}}$ **(3)**	$\mathbf{7.2 \times 10^9}$ **(2)**	$\mathbf{1.6 \times 10^{11}}$ **(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 $SC\text{-}CO_2$ ($ = USD)	Degree of Weathering and Soil Development					
		Slight			Moderate		Strong
		Entisols	Inceptisols	Histosols	Alfisols	Mollisols	Spodosols
		$SC\text{-}CO_2$ ($ = 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	$\mathbf{6.5 \times 10^{10}}$	$\mathbf{2.0 \times 10^9}$	$\mathbf{1.9 \times 10^{10}}$	$\mathbf{1.4 \times 10^{10}}$	$\mathbf{1.8 \times 10^9}$	$\mathbf{1.2 \times 10^9}$	$\mathbf{2.7 \times 10^{10}}$

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, Figures 3 and 4), resulting in GHG emissions from soils. 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 (Tables 12 and 13). 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 VT, and its county seat, the city of Burlington, is the most populous municipality in the state.

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	30.4 (−2.3%)	6.1 (−1.1%)	10.6 (1.9%)	1.0 (−38.2%)	1.5 (−1.9%)	0.2 (2.9%)	11.1 (−1.6%)
Woody wetlands	1035.9 (−1.0%)	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	280.5 (188.1%)	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 (−0.4%)	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	8700.7 (−2.3%)	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	222.6 (124.4%)	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	3045.0 (−1.9%)	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 (9.3%)	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	2702.5 (−4.4%)	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	412.7 (25.2%)	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	813.9 (0.4%)	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	161.6 (7.3%)	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	385.4 (1.5%)	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	35.9 (12.5%)	9.2 (10.1%)	13.8 (14.1%)	0.2 (19.2%)	1.9 (18.0%)	0.2 (64.6%)	10.6 (10.9%)

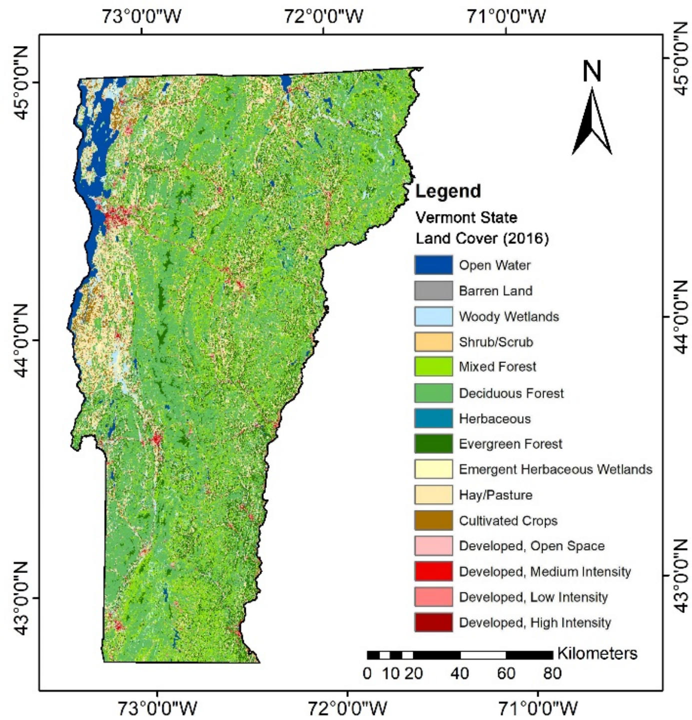


Figure 3. Land cover map of Vermont (U.S.A.): 2016 (Latitude: 42° 44′ N to 45° 1′ N; Longitude: 71° 28′ W to 73° 26′ W) (based on data from (Multi-Resolution Land Characteristics Consortium—MRLC n.d.)).

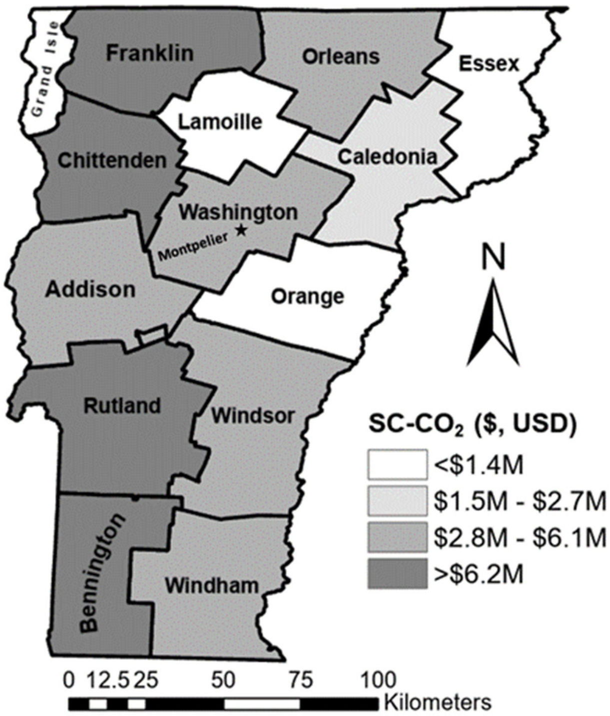


Figure 4. Realized total dollar value of mid-point total soil carbon (TSC) for newly "developed" land covers (open space, low, medium, and high intensity) from 2001 to 2016 in Vermont (U.S.A.) based on a social cost of C (SC-CO_2) of $46 per metric ton of CO_2 applicable for the year 2025 (2007 U.S. dollars with an average discount rate of 3% (EPA—United States Environmental Protection Agency 2016a)).

Table 12. Increases in developed land and maximum potential for realized social costs of carbon due to complete loss of total soil carbon (TSC) 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, km² ($SC\text{-}CO_2$, $ = 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, Alfisols, Mollisols, and Spodosols are mineral soils. Histosols are mostly organic soils. M = million = 10^6.

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 (TSC) of developed land by soil order and county in Vermont (USA) from 2001 to 2016.

County	Total Area Change (km²) ($SC\text{-}CO_2$, $ = USD)	Degree of Weathering and Soil Development					
		Slight			Moderate		Strong
		Entisols	Inceptisols	Histosols	Alfisols	Mollisols	Spodosols
		Developed Area Increase between 2001 and 2016 (km²)					
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**

4. Significance of Results for Vermont's Climate Policy

The state of VT is experiencing significant impacts from climate change (EPA—United States Environmental Protection Agency 2016b). The Vermont Global Warming Solutions Act (GWSA, 2020) sets GHG emissions reduction targets for energy-related emissions only, but authorizes the 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 the 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., CO_2 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.

The amount and social cost of CO_2 emissions from land disturbance in VT are substantial with a total of $61.8 million from 2001 to 2016 (Tables 12 and 13). Moreover, the developed methodology can attribute the sources of these emissions at a level that is specific: not only for VT as a whole, but also for specific developments, businesses, and even homes. Developed methodology permits ready calculation of the COI both for VT as a whole, and for Vermont's failure to regulate land disturbance in specific counties and for specific projects.

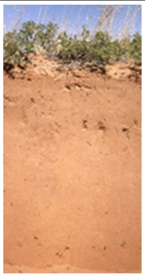
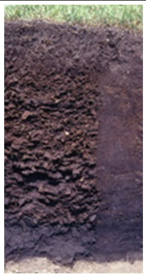
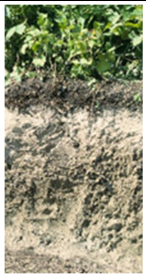
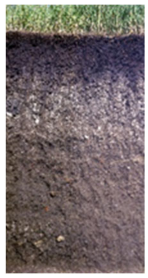
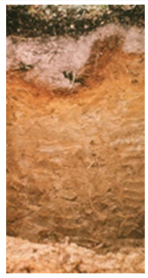
In VT, this new information could have an important legal impact. It would permit VT to incorporate into its regulations control of GHG emissions from land disturbance. Vermont's GWSA imposes tight restrictions on GHG from fossil fuels, requiring a 40% reduction by 2030 and an 80% reduction by 2050 (GWSA 2020). In addition, Vermont's law encourages sequestration, where additional tree coverage is encouraged that will absorb GHG emissions. The absence of regulation of land disturbance is an important oversight. Vermont lawmakers could now revise the GWSA to regulate this important additional source of GHG emissions. Vermont might well do this because the COI is substantial and can now be readily calculated. Additional regulation might take the form of limits on development, especially in areas with soils that release large amounts of GHG when disturbed (Table 10) and in counties with much more development (Table 13).

In addition, new regulation might be in the form of additional fees that would be imposed on developers that would reflect the full social costs of GHG emissions from land disturbance from their development projects. The fees could be based on the type of soil in each county or municipality. Currently, a developer pays none of the additional social cost of released GHG from a development's land disturbance. Basic economic principles demonstrate that when economic actors do not pay the full cost of their conduct, then they tend to do much of it. Accordingly, one of the COI on charging development fees that reflect the full social cost of land disturbance is that there is an inefficiently large amount of development in VT, as developers proceed with some projects that have negative net social value. It may seem counterintuitive to argue that excessive development occurs in VT, a state with a population of low density. However, this study and simple economics show that this must be so, since developers are not bearing the full cost that their development imposes.

5. Significance of Results in Broader Context

Not only in VT, but also in other states and countries outside the United States, 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 inaction 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. 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."

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): $55.0B					
$1.2B	$12.0B	$14.2B	$1.1B	$652.1M	$25.7B
2%	22%	26%	2%	1%	47%
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	High	Low
SOC and SIC sequestration (recarbonization) potential					
Low	Low	Low	Low	Low	Low

Note: Entisols, Inceptisols, Alfisols, Mollisols, and Spodosols are mineral soils. Histosols are mostly organic soils. M = million = 10^6; B = billion = 10^9.

Damages from land conversions can be variable with numerous economic, environmental, societal, and legal impacts (Figure 5). Figure 5 provides some examples of possible damages from soil emissions because of land conversions. Direct physical damages include carbon loss and increasing temperatures (Figure 5). In addition, a state's cost of borrowing can increase if a state suffers a climate crisis-related credit downgrade. Such a downgrade is an example of indirect tangible damage because of insufficient strategies to address climate change (Figure 5)—which is a cost of inaction.

Policymakers are increasingly facing the daunting task of budgeting for climate-change-related expenses. The extent and intensity of climate change and its contributing factors vary 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 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 6 shows the value of TSC based on two possible scenarios: (1) the cost of action (avoided social cost) by sequestering carbon in the soil, and (2) the cost of inaction (realized social cost) by releasing emissions into 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 worst possible case for inaction—if all of a state's land was disturbed, and all of its carbon would be released.

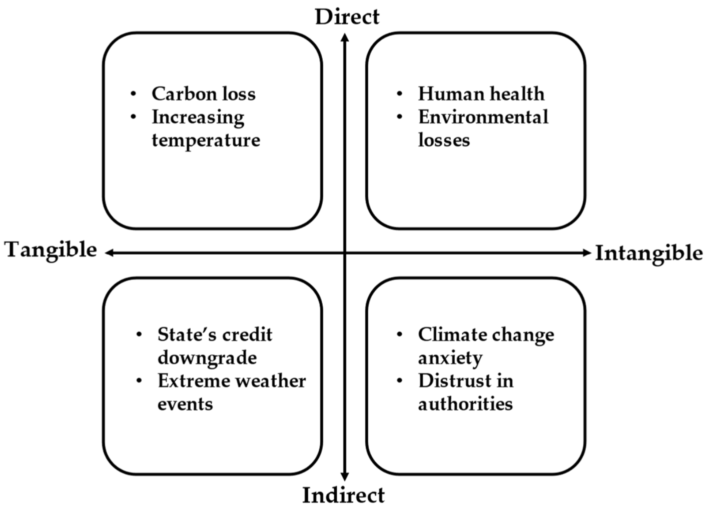


Figure 5. Examples of tangible, intangible, direct, and indirect emissions damages, which can include emissions from land conversions (adapted from Nicklin et al. 2019).

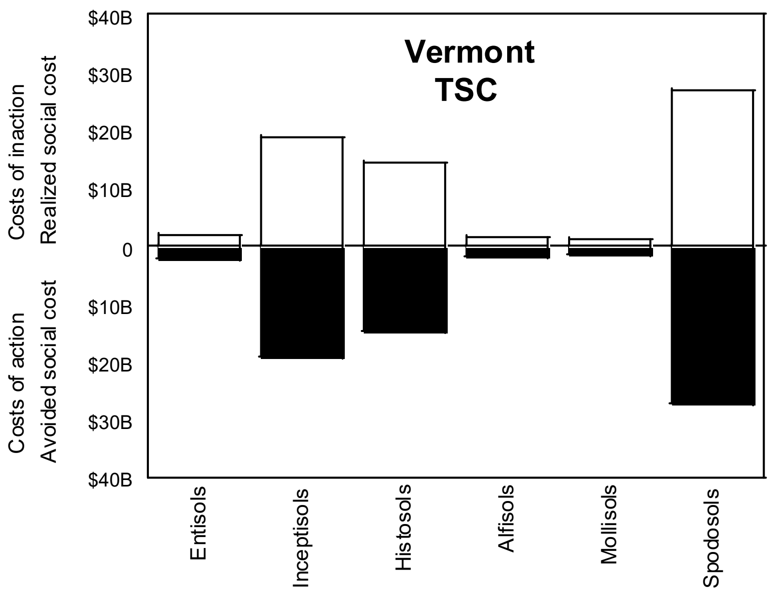


Figure 6. Comparison of costs of action (avoided social costs) with costs of inaction (realized social costs) using the monetary value of total soil carbon (TSC) storage or potential cost if all TSC is released as CO_2 emissions. Monetary valuation is based on soil C in the upper 2-m depth and a social cost of CO_2 emission of $46 (USD) per metric ton of CO_2 applicable for the year 2025 (2007 U.S. dollars with an average discount rate of 3% (EPA—United States Environmental Protection Agency 2016a)). Note: B = billion = 10^9.

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.

Another COI will be that inaction will expose states, local governments, and private parties to environmental lawsuits. In recent years, there has been an explosion in such lawsuits. These have been of two kinds. The first are lawsuits against public bodies, such as the Environmental Protection Agency (EPA) at the federal level, or environmental agencies at the state level. Such lawsuits have been filed in the U.S. and throughout the world (United Nations Environment Programme 2017). Some have succeeded. For example, in *Urgenda Foundation v. The State of the Netherlands* (2018), a Dutch court ordered the government to seek a greater reduction in GHG, because a failure to do so would breach the government's general duty to protect its people from the harms of climate change (Upadhyay 2019). Some of these suits have been based on general human rights laws or national or state constitutions.

However, greater success has been enjoyed by lawsuits that invoke specific environmental laws (Upadhyay 2019). A lawsuit that asserts that a government's environmental policies are violating specific provisions in a specific environmental statute is easier to win than a suit that asserts that GHG emissions are violating a constitution's general requirements of "human rights," "equality," or a "right to life."

All such suits face difficulty in the U.S. because of doctrines of governmental immunity or "sovereign immunity," through the 11th Amendment for states, and through statutes and judge-made common law for counties and municipalities (Klein 2015). Although a suit's path to success is a difficult one, a suit can in certain circumstances, succeed despite the high hurdle of sovereign immunity. For example, in some states, sovereign immunity bars suits that seek money damages, but not suits that seek injunctive relief; injunctive relief is an order requiring the governmental entity not to pay money to the plaintiffs, but instead to do something, such as reducing GHG (Klein 2015).

Our research would make a state such as VT, with a strong environmental statute with specific goals for GHG reduction, a relatively easy target for lawsuits. Although the Vermont's GWSA's strict targets for 90% reduction by 2050 apply only to energy-related GHG emissions, the statute also includes very general language that speaks of the great harms of all GHG emissions (General Assembly of the State of Vermont 2020). Competent plaintiff's attorneys could readily assert claims that, now that the extent of GHG emissions from land disturbance in VT is known, the GWSA explicitly or implicitly requires reduction in such emissions.

Another COI would be exposure to a second class of lawsuits: suits filed not against the government but against private individuals and businesses. The developed methodology can estimate with precision not just GHG emissions from land disturbance for the state as a whole, but also for specific business locations and homes. Armed with such data, plaintiffs could assert that a specific development—such as a housing subdivision—released GHG that harmed the plaintiffs. Such lawsuits face hurdles of proving the elements of a negligence claim: duty, breach, causation, and injury (Hunter and Salzman 2007).

So far, despite occasional success in other countries, lawsuits against both governments and businesses for releasing GHG through burning fossil fuels have generally not succeeded in U.S. courts. For example, in *Juliana v. United States* (2020), the plaintiffs sued the U.S. federal government to require it to impose a comprehensive plan to control GHS emissions. After winning in the trial court, the suit was dismissed on appeal, with the Ninth Circuit holding that plaintiffs lacked standing to seek such a comprehensive revision of national climate law. Despite setbacks, plaintiffs continue to file additional suits, both against governments and against private entities. For example, in *Rhode Island v. Chevron Corp*

(2019), the state of Rhode Island is suing 21 oil companies, asserting that the companies have caused releases of GHG that have harmed the state.

Such suits may eventually succeed, as did suits against tobacco manufacturers after many years of failure. Or they may not. Regardless of whether the lawsuits are successful, defending against the lawsuits will be expensive for both public and private defendants in terms of attorneys' fees and disruption to normal activities. By acting quickly to regulate GHG gas emissions from land disturbance, both public and private defendants in VT could avoid the substantial COI of defending litigation.

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 an 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 the cost of action versus inaction with regard to soil-based emissions because of land conversions. The estimated total monetary mid-point value for TSC stocks in VT was \$65.3B (i.e., 65.3 billion U.S. dollars (USD), where B = billion = 10^9), \$55.0B for SOC stocks, and \$10.3B for SIC stocks. Soil orders with the highest midpoint value for SOC were Spodosols (\$25.7B), 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 (\$7.2B), Windham (\$5.2B), and Rutland (\$5.0B). 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-CO_2 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-CO_2 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 the rapid assessment of the soil carbon inventory and soil-related GHG emissions on a regular basis to monitor the compliance with the greenhouse gas (GHG) emissions reduction targets set by the state of VT. 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.

The results provide a ready means and motive for VT to begin to regulate land disturbance more carefully, demonstrating that COI of continuing its present regulatory inaction may expose VT's state and local governments, as well as private businesses, to an increased risk of becoming defendants in environmental lawsuits.

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Glossary

ED	Ecosystem disservices
ES	Ecosystem services
EPA	Environmental Protection Agency
SC-CO_2	Social cost of carbon emissions
SDGs	Sustainable Development Goals
SOC	Soil organic carbon
SIC	Soil inorganic carbon
SOM	Soil organic matter
SSURGO	Soil Survey Geographic Database
TSC	Total soil carbon
USDA	United States Department of Agriculture
U.S.A.	United States of America

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