geographies

MDPI

Article

Net-Zero Target and Emissions from Land Conversions: A Case Study of Maryland's Climate Solutions Now Act

Philip C. Hutton [1], Elena A. Mikhailova [1,*], Lili Lin [2], Zhenbang Hao [3], Hamdi A. Zurqani [4], Christopher J. Post [1], Mark A. Schlautman [5] and George B. Shepherd [6]

1. Department of Forestry and Environmental Conservation, Clemson University, Clemson, SC 29634, USA
2. Department of Biological Science and Biotechnology, Minnan Normal University, Zhangzhou 363000, China
3. University Key Lab for Geomatics Technology and Optimized Resources Utilization in Fujian Province, Fuzhou 350002, China
4. University of Arkansas Agricultural Experiment Station, Arkansas Forest Resources Center, University of Arkansas at Monticello, Monticello, AR 71655, USA
5. Department of Environmental Engineering and Earth Sciences, Clemson University, Anderson, SC 29625, USA
6. School of Law, Emory University, Atlanta, GA 30322, USA

* Correspondence: eleanam@clemson.edu

Abstract: Many climate change "solution" plans include net-zero goals, which involve balancing the anthropogenic greenhouse gas emissions (GHG) with their removal. Achieving net-zero goals is particularly problematic for soils because they are often excluded from GHG inventories and reduction plans. For example, Maryland's Climate Solutions Now Act (Senate Bill 528) put forward the goal of lowering emissions of GHG to 60% under 2006 quantities by 2031 and with a target of net-zero emissions by 2045. To achieve these goals, the state of Maryland (MD) needs to quantify GHG emissions from various sources contributing to the state's total emissions footprint (EF). Soils are currently excluded from MD's GHG assessments, which raises a question about how the soil impacts the net-zero goal. This study examines the challenges in meeting net-zero goals using an example of carbon dioxide (CO_2) as one of the GHG types (net-zero CO_2 emissions). The current study quantified the "realized" social costs of CO_2 (SC-CO_2) emissions for MD from new land developments in the period from 2001 to 2016 which caused a complete loss of 2.2×10^9 kg of total soil carbon (TSC) resulting in \$383.8M (where M = million, USD = US dollars). All MD's counties experienced land developments with various emissions and SC-CO_2 monetary values. Most of the developments, TSC losses, and SC-CO_2 occurred near the existing urban areas of Annapolis and Baltimore City. These emissions need to be accounted for in MD's GHG emissions reduction plans to achieve a net-zero target. Soils of MD are limited in recarbonization capacity because 64% of the state area is occupied by highly leached Ultisols. Soil recarbonization potential is further reduced by urbanization with Prince George's, Montgomery, and Frederick counties experiencing the highest increases in developed areas. In addition, projected sea-level rises will impact 17 of MD's 23 counties. These losses will generate additional social costs because of migration, costs of relocation, and damages to infrastructure. The state of MD has a high proportion of private land ownership (92.4%) and low proportion of public lands, which will limit opportunities for relocation within the state. Net-zero targets are important but meeting these targets without specific and integrative approaches depending on the source and type of emissions may result in failure. These approaches should also focus on the social costs of emissions, which raises the need for a new concept of integrating net-zero emissions and social costs.

Keywords: carbon; CO_2; change; footprint; goal; greenhouse gas; law; market; neutrality; policy

Citation: Hutton, P.C.; Mikhailova, E.A.; Lin, L.; Hao, Z.; Zurqani, H.A.; Post, C.J.; Schlautman, M.A.; Shepherd, G.B. Net-Zero Target and Emissions from Land Conversions: A Case Study of Maryland's Climate Solutions Now Act. *Geographies* **2023**, *3*, 40–59. https://doi.org/10.3390/geographies3010003

Academic Editor: Xu Chen

Received: 28 October 2022
Revised: 1 December 2022
Accepted: 23 December 2022
Published: 29 December 2022

1. Introduction

The net-zero emissions goal is a scientific concept, which has a wide range of interpretations which depends on the source and type of emissions [1,2]. In general, net-zero is defined as the net balance between emissions and removals over a defined time period [3].

Solving a net-zero equation is a complex task because it involves balancing numerous types and sources of emissions and removals [1]. Soils can be a considerable source of emissions upon disturbance, which can be determined by spatial analysis of land cover change and soil types in a specified area of interest (Figure 1) [4]. Although net-zero is a clear goal, the methodology for achieving this goal is much less clear. This study examines carbon (C) emissions and proposes to use the concept of carbon footprint (CF) from soils over a defined time period to determine if there are CO_2 emissions from land cover changes which can be either net CO_2 zero, CO_2 positive, or CO_2 negative. Areas with land disturbances can be identified using remote sensing analysis, which can be linked to soil types with various soil C amounts to estimate disturbance-linked emissions. This analysis can also identify any land cover conversions that may have increased C storage, such as an increase in forest or grassland land cover types (Figure 1).

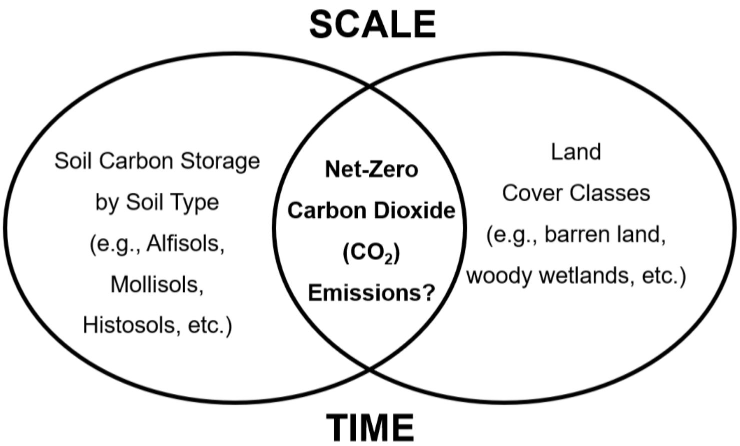

Figure 1. Net-zero carbon dioxide (CO_2) emissions from soils can be defined as a balance between the carbon footprint (CF), which is the intersection between land cover classes and soil C storage by soil type with anthropogenic/natural disturbance, and any C removal by soil. If the CF does not change over time, there is net-zero CO_2 emissions from soils (modified from Mikhailova et al., 2022 [4]).

The Relevance of Soils to Maryland's Greenhouse Gas Emissions Reduction Act

Since the enactment in 2016 of the United Nations' Paris Climate Agreement, an international plan for limiting global warming, the term "net-zero" has increasingly been used as a target for countries, institutions, and companies in their respective emissions goals [5]. The net-zero concept is important for climate change planning and preparations [1]. For example, the State of Maryland (MD) passed its Climate Solutions Now Act (Senate Bill 528) which established a goal of lowering GHG losses to 60% under 2006 quantities by 2031 and with a target of net-zero emissions by 2045 [6]. Emissions of GHG from soils because of land developments are often overlooked in net-zero goals, which is a serious limitation.

Pedodiversity of MD (soil composition) is important in achieving the net-zero goal because it defines the maximum natural capacity for regulating ecosystem services or disservices (ES or ED), which relates to the soil's maximum ability to store or release CO_2 (Table 1, Figure 2) [7]. The state of MD has three slightly weathered soils (Entisols, Histosols, Inceptisols), one moderately weathered (Alfisols), and two strongly weathered (Spodosols, Ultisols) soils, which have various soil C contents and sensitivities to climatic change. Sassafras (soil order: Ultisols) is the state soil of MD, and this soil was selected for its importance to agriculture and forestry [8].

Table 1. Soil taxonomic variety and ecosystem services (provisioning, regulation/maintenance, cultural) in Maryland (USA) (modified based on Mikhailova et al., 2021 [7]).

Stocks		Area	Ecosystem Services
Soil Order	**General Characteristics and Constraints**	**(km^2)**	
	Slightly Weathered	**5160.1**	
Entisols	Embryonic soils with ochric epipedon	1524.0	+
Inceptisols	Young soils with ochric or umbric epipedon	3357.9	+
Histosols	Organic soils with ≥20% of organic carbon	278.2	+
	Moderately Weathered	**2829.8**	
Alfisols	Clay-enriched B horizon with B.S. ≥35%	2829.8	+
	Strongly Weathered	**14,701.3**	
Spodosols	Coarse-textured soils with albic and spodic horizons	242.6	+
Ultisols	Highly leached soils with B.S. <35%	14,458.6	+

Note: B.S. = base saturation.

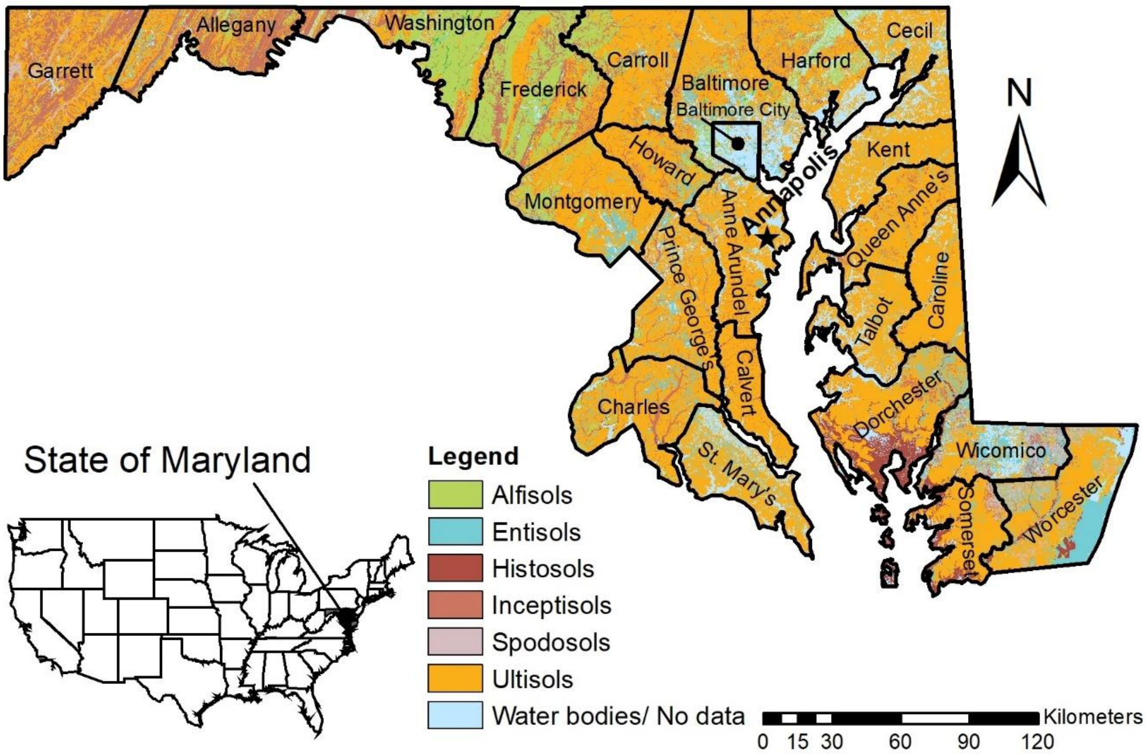

Figure 2. General soil map of Maryland, USA (37°53′ N to 39°43′ N; 75°03′ W to 79°29′ W) based on the SSURGO soils database [9] with counties boundary shown [10].

Achieving a net-zero goal in MD is also complicated by the ownership of the soil and land, which are largely privately owned (92.4%) (18 U.S. states have more than 90% of land in private ownership) [11]. Eastern parts of MD have experienced increased urbanization at the loss of agricultural and barren land cover, which also has contributed to elevated sewage loading to surface water [12]. Sexton et al. (2013) [13] documented urban growth in the Baltimore, Washington, D.C., and MD metro area by remarkable growth of impervious cover revealed by the Landsat-based analysis.

The present study hypothesizes that the soil-associated emissions resulting from land developments should be included in the net-zero target calculations. Our study uses newly determined estimates of CO_2 emission from soils from land developments between 2001 and 2016 for the state of MD developed by an analysis using remote sensing and spatial data to determine soil C contributions to the net-zero target. Our study will demonstrate how emissions data with a spatially explicit context can be used to quantify the amount of C, which needs to be removed from the atmosphere as well as its monetary valuations for the social costs associated with CO_2 (SC-CO_2) emissions.

This study's objectives were to estimate: (1) the storage and social cost of soil inorganic carbon (SIC), soil organic carbon (SOC), and total soil carbon (TSC) within MD, USA; and (2) the CF determined by the soil C difference over 15 years based on land cover change. This soil CF represents the amount of CO_2 released which needs to be otherwise sequestered to meet the net-zero CO_2 emissions goal. Any soil CO_2 emissions that are not sequestered represent damages that can be described by the social cost of C (SC–CO_2) concept. The U.S. Environmental Protection Agency (EPA) has assigned the SC–CO_2 as $46 per metric ton of CO_2, applicable for 2025 based on 2007 U.S. dollars and an average discount rate of 3% [14]. Our calculations provide estimates throughout the state and at various spatial resolutions (e.g., state) utilizing the State Soil Geographic (STATSGO), and the Soil Survey Geographic Database (SSURGO) databases as well as previously reported data by Guo et al. (2006) [15].

2. Materials and Methods

The current study utilizes administrative (boundary-based: U.S. County boundaries, Figure 2) and biophysical (science-based: soil classification, Figure 2) units of analysis to calculate the SIC, SOC, and TSC monetary values (Tables 2 and 3). This research determines values calculated from SIC, SOC, and TSC stocks in MD using published soil C contents (in kg m^{-2}) provided by Guo et al. (2006) [15]. These values were determined by utilizing the social cost of carbon (SC-CO_2) value of $46 per metric ton of CO_2, valid until 2025, which was calculated using 2007 U.S. dollars with an average discount rate of 3% [14].

Table 2. A description of the accounting framework (modified from Groshans et al. (2019) [16]) adapted for net-zero (e.g., net-zero carbon dioxide (CO_2) emissions) target accounting.

OWNERSHIP (e.g., single, shared, government, foreign, private, etc.)					
	STOCKS/SOURCE ATTRIBUTION		**FLOWS**		**VALUE**
Timeline (e.g., information disclosures, etc.)	**Science-Based Biophysical Stocks**	**Boundary-Based Administrative Stocks**	**Monetary Accounts**	**Benefits/ Damages**	**Total Values**
	Soil extents:	Administrative extents:	Ecosystem good(s) and service(s):	Sector:	Type of value:
	Total stock: Total soil carbon (TSC) = Soil inorganic carbon (SIC) + Soil organic carbon (SOC)				
Past (e.g., after land development disclosure) **Current** (e.g., status) **Future** (e.g., before land development disclosure)	- Soil orders (Entisols, Inceptisols, Histosols, Alfisols, Spodosols, Ultisols)	- State (Maryland) - County (23 counties)	- Regulation (e.g., carbon release, carbon sequestration)	Environment: - Carbon sequestration, Carbon loss	The social cost of carbon (SC-CO_2) emissions: - $46 per metric ton of CO_2 applicable for the year 2025 (2007 U.S. dollars, with an average discount rate of 3% [14])
			Carbon Footprint Change: Net-zero carbon dioxide (CO_2) emissions?		**Carbon Footprint Change:** Net-zero social costs from carbon dioxide (CO_2) emissions ($)?

Table 3. Areas of soil orders by county in Maryland (USA) from the Soil Survey Geographic (SSURGO) Database [9].

County/City	Total Soil Area (km^2) (%)	Degree of Weathering and Soil Development					
		Slight			Moderate	Strong	
		Entisols	Inceptisols	Histosols	Alfisols	Spodosols	Ultisols
		2016 Area (km^2), (% of Total County Area)					
Allegany	1028.3(5)	51.8(5)	551.6(54)	0	95.4(9)	0	329.6(32)
Anne Arundel	883.6(4)	39.5(4)	92.3(10)	6.8(1)	40.2(5)	0	704.6(80)
Baltimore City	111.9(0)	25.7(23)	7.0(6)	0(0)	29.3(26)	0	49.8(45)
Baltimore	1313.1(6)	183.0(14)	167.7(13)	6.9(1)	136.5(10)	0	819.0(62)
Calvert	546.0(2)	43.0(8)	235.9(43)	11.2(2)	5.4(1)	0	250.6(46)
Caroline	632.5(3)	50.8(8)	20.8(3)	3.2(1)	3.1(0)	0	554.5(88)
Carroll	1109.4(5)	33.2(3)	115.0(10)	0	172.3(16)	0	788.9(71)
Cecil	712.6(3)	46.1(6)	28.3(4)	0	49.9(7)	0	588.3(83)
Charles	1174.6(5)	88.7(8)	123.8(11)	0	38.8(3)	0	923.3(79)
Dorchester	1365.4(6)	119.7(9)	52.0(4)	132.1(10)	232.1(17)	0	829.6(61)
Frederick	1621.8(7)	16.2(1)	273.0(17)	0	833.6(51)	3.9(0)	495.1(31)
Garrett	1660.7(7)	37.1(2)	551.7(33)	0	93.6(6)	53.0(3)	925.3(56)
Harford	939.6(4)	4.5(0)	270.1(29)	20.7(2)	131.7(14)	0	512.6(55)
Howard	564.8(2)	33.2(6)	123.1(22)	0	16.8(3)	0	391.7(69)
Kent	654.5(3)	35.8(5)	0.2(0)	8.4(1)	0	0	610.1(93)
Montgomery	1260.0(6)	63.7(5)	143.5(11)	0	82.5(7)	0	970.2(77)
Prince George's	1067.8(5)	118.3(11)	115.9(11)	0	4.5(0)	0	829.1(78)
Queen Anne's	946.7(4)	49.2(5)	75.2(8)	7.1(1)	6.7(1)	0	808.5(85)
Somerset	733.8(3)	49.3(7)	1.3(0)	9.0(1)	157.9(22)	24.4(3)	491.9(67)
St. Mary's	746.7(3)	43.7(6)	54.9(7)	0	0	0	648.0(87)
Talbot	494.2(2)	3.5(1)	0	6.5(1)	11.5(2)	0	472.7(96)
Washington	1119.8(5)	17.5(2)	178.9(16)	0	644.8(58)	0.2(0)	278.5(25)
Wicomico	825.5(4)	140.6(17)	175.5(21)	9.4(1)	43.3(5)	28.5(3)	428.2(52)
Worcester	1177.9(5)	229.9(20)	0.2(0)	56.8(5)	95.4(0)	132.7(11)	758.4(64)
Totals	**22,691.2(100)**	**1524.0(7)**	**3357.9(15)**	**278.2(1)**	**2829.8(12)**	**242.6(1)**	**14,458.6(64)**

Based on the US Environmental Protection Agency (EPA), the SC-CO_2 was developed to provide an estimate of damages associated with climate change. However, it likely underestimates the actual future damages and cost of CO_2 emissions because this estimate excludes multiple climate change impacts that have been identified in the literature [14]. Equation (1) was used to calculate area-normalized values ($\$ \ m^{-2}$), and the total USD values were then summed for the corresponding areas (a metric tonne is equal to one megagram (Mg) or 1000 kilograms (kg), and SC = soil carbon, e.g., SIC, SOC, or TSC):

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

Values ($\$ \ m^{-2}$; Table 4) and area-normalized contents (kg m^{-2}) of soil carbon were then used to estimate their monetary values and stocks of SIC, SOC, and TSC by multiplying the area of the soil order in a county by the contents/values (Table 3). As an example, for the Alfisols, Guo et al. (2006) [15] reported a midpoint SOC content of 7.5 kg m^{-2} in the upper 2-m soil depth (Table 4). Using this SOC content in Equation (1) results in an area-normalized SOC value of \$1.27 m^{-2}. Multiplying the total area of Alfisols present in MD (2829.8 km^2, Table 3) by the SOC content with its corresponding area-normalized value results in a calculated SOC stock of 2.1×10^{10} kg with a monetary value of \$3.6B.

Table 4. Area-normalized values (\$ m^{-2}) and carbon (C) content (kg m^{-2}) of soil organic C (SOC), soil inorganic C (SIC), and total soil C (TSC = SOC + SIC) using values provided by Guo et al. (2006) [15] for the upper 2-m of soil and using an avoided social cost of carbon (SC-CO_2) value of \$46 per CO_2 metric ton, applicable until 2025 (2007 U.S. dollars, with an average discount rate of 3% [14]).

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
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
Ultisols	1.9—7.1—13.9	0.0—0.0—0.0	1.9—7.1—13.9	1.20	0.00	1.20

The change in land cover from 2001 to 2016 for MD was analyzed using the already classified Landsat satellite images created by the Multi-Resolution Land Characteristics Consortium (MRLC), which reported an overall classification accuracy of 91% [17]. Soil type association and land cover change were analyzed using ArcGIS Pro 2.6 GIS software [18] by finding the difference between the 2001 and 2016 land cover layers and then converting from raster to vector format. The Soil Survey Geographic (SSURGO) Database [9] was used to derive the soil layer that was unioned with the vectorized land cover data.

3. Results and Discussion

The estimated total mid-point TSC storage was 4.9×10^{11} kg with a social value of \$41.4B (i.e., 41.4 billion USD, where B = billion = 10^9); 2.1×10^{11} kg for SOC (\$35.1B, 85% of the total value), and 3.7×10^{10} kg for SIC (\$6.3B, 15% of the total value) for the state of MD (Tables S1–S3). We previously found that within the 48 contiguous U.S. states, MD ranked 42nd for TSC [19], 42nd for SOC [20], and 48th for SIC [16].

3.1. Soil Organic Carbon (SOC) Storage and Value in Maryland

The soil orders with the largest midpoint storage and value for SOC were Ultisols (1.0×10^{11} kg, \$17.4B), Histosols (3.9×10^{10} kg, \$6.6B), and Inceptisols (3.0×10^{10} kg, \$5.0B) (Table S1). Ultisols contributed 49% of the SOC, which was followed by Histosols (19%), and finally, Inceptisols (14%). The highest calculated midpoint SOC values for counties were found in Dorchester (\$4.7B), Worcester (\$2.8B), and Garrett (\$2.2B) (Table S1). Dorchester contributed 13% of the state's total SOC, followed by Worcester (8%), and Garrett (6%). Dorchester has the largest areas of C-rich Histosols with 132.1 km^2 (Table 3).

3.2. Soil Inorganic Carbon (SIC) Storage and Value in Maryland

The soil orders with the largest midpoint storage and value for SIC were Inceptisols (1.7×10^{10} kg, \$2.9B), Alfisols (1.2×10^{10} kg, \$2.0B), and Entisols (7.3×10^9 kg, \$1.2B) (Table S2). Inceptisols contributed 46% of SIC, followed by Alfisols (32%), and Entisols (20%). The largest midpoint SIC values were found in the counties of Frederick (\$848.6M), Washington (\$632.5M), and Allegany (\$585.4M) (Table S2).

3.3. Total Soil Carbon (TSC = SOC + SIC) Storage and Value in Maryland

Soil orders having the largest midpoint storage and value for TSC were Ultisols (1.0×10^{11} kg, \$17.4B), Inceptisols (4.7×10^{10} kg, \$7.9B), and Histosols (4.0×10^{10} kg, \$6.7B) (Table S3). Ultisols contributed 42% of TSC, followed by Inceptisols (19%), and

Histosols (16%). Dorchester ($5.0B), Worcester ($3.1B), and Frederick ($2.9B) counties had the highest midpoint TSC values (Table S3). An overall summary of the soil carbon regulating ES for the state of MD is reported in Table 5. Slightly weathered soils (23% of the total soil area) have the most of TSC and associated social costs of C (Table 5).

Table 5. Soil carbon regulating ecosystem service distribution for Maryland, USA (photos courtesy of USDA/NRCS [21]).

Soil Regulating Ecosystem Services in the State of Maryland					
Degree of Weathering and Soil Development					
Slight 23%			**Moderate 12%**	**Strong 65%**	
Entisols 7%	**Inceptisols 15%**	**Histosols 1%**	**Alfisols 12%**	**Spodosols 1%**	**Ultisols 64%**
					
Soil organic carbon (SOC) social cost: $35.1B					
$2.1B	$5.0B	$6.6B	$3.6B	$502.3M	$17.4B
6%	14%	19%	10%	1%	49%
Soil inorganic carbon (SIC) social cost: $6.3B					
$1.2B	$2.9B	$114.1M	$2.0B	$24.3M	$0.0
20%	46%	2%	32%	0%	0%
Total soil carbon (TSC) social cost: $41.1B					
$3.3B	$7.9B	$6.7B	$5.6B	$526.5M	$17.4B
8%	19%	16%	14%	1%	42%
Sensitivity to climate change					
Low	Low	High	High	Low	Low
SOC and SIC sequestration (recarbonization) potential					
Low	Low	Low	Low	Low	Low

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

3.4. Land Development Change for Maryland between 2001 and 2016

Maryland had extensive land development throughout the 15-year study period (Table 6, Figure 3), resulting in GHG emissions. These changes differed both in original landcover class and soil order, with the majority of soil orders seeing losses in "low disturbance" landcover classes (e.g., hay and pasture, evergreen forest) while having increases in locations associated with "developed" land cover categories. The landcover classes with the largest increases were the high-intensity (+29.1%), and medium-intensity (+25.1%) developed classes (Table 6). Changes also varied by soil order. In the high-intensity developed class, the soil orders with the largest increases included Histosols (+313.6%), Alfisols (+54.9%), and Ultisols (+43.5%). The soil order of Histosols is composed of C-rich wetland soils, which are often protected from development by federal and state laws. The soil order of Alfisols often supports agricultural uses and should likely continue to be used for this purpose.

Table 6. Land use/land cover (LULC) change by soil order in Maryland (USA) from 2001 to 2016.

NLCD Land Cover Classes (LULC)	2016 Total Area by LULC (km^2) (Change in Area, 2001–2016, %)	Degree of Weathering and Soil Development					
		Slight			Moderate	Strong	
		Entisols	Inceptisols	Histosols	Alfisols	Spodosols	Ultisols
		2016 Area by Soil Order, km^2 (Change in Area, 2001–2016, %)					
Barren land	70.3(−1.9)	30.3(−0.5)	6.8(1.6)	0.0(23.1)	3.9(−20.1)	0.6(11.7)	28.7(−1.4)
Woody wetlands	2464.5(2.6)	266.1(3.4)	379.3(0.9)	128.8(1.3)	109.3(6.5)	110.7(1.9)	1470.3(2.9)
Shrub/Scrub	147.7(−22.2)	11.8(−39.0)	23.0(−16.2)	0.0(−40.7)	8.1(−14.9)	1.7(−37.4)	103.1(−21.2)
Mixed forest	2222.2(1.2)	122.0(2.1)	435.7(1.5)	0.6(0.7)	249.0(1.2)	10.9(5.4)	1404.0(0.9)
Deciduous forest	5338.0(−2.8)	174.8(−5.0)	1381.9(−1.2)	1.0(−4.7)	445.1(−2.8)	44.5(−1.9)	3290.8(−3.4)
Herbaceous	116.6(60.3)	11.2(13.5)	20.1(78.7)	0.2(38.6)	8.2(150.8)	1.4(16.3)	75.5(60.6)
Evergreen forest	579.8(7.6)	71.1(9.4)	56.5(9.5)	0.3(−6.3)	24.8(−0.1)	12.8(14.9)	414.4(7.3)
Emergent herbaceous wetlands	725.2(−8.9)	100.1(−9.7)	15.6(−17.2)	141.2(−1.5)	363.6(−1.8)	0.7(−76.6)	104.0(−30.5)
Hay/Pasture	2436.3(−7.8)	62.1(−11.6)	394.2(−6.4)	0.0(−22.2)	612.1(−8.6)	1.6(−0.9)	1366.3(−7.6)
Cultivated crops	4786.9(1.0)	220.8(−1.5)	310.6(4.1)	0.9(−1.5)	564.4(4.8)	47.6(−2.6)	3642.7(0.4)
Developed, open space	2141.8(2.7)	156.7(−1.0)	230.4(2.4)	3.0(−2.2)	225.1(4.9)	7.9(4.1)	1518.8(2.9)
Developed, medium intensity	446.1(25.1)	117.3(11.2)	21.3(31.6)	0.5(96.0)	49.0(34.2)	0.5(58.4)	257.5(30.1)
Developed, low intensity	1081.4(6.9)	126.7(2.8)	77.6(6.1)	1.4(−3.9)	153.9(8.1)	1.6(8.8)	720.2(7.5)
Developed, high intensity	134.3(29.1)	53.2(10.2)	4.9(43.5)	0.2(313.6)	13.4(54.9)	0.2(112.6)	62.5(43.5)

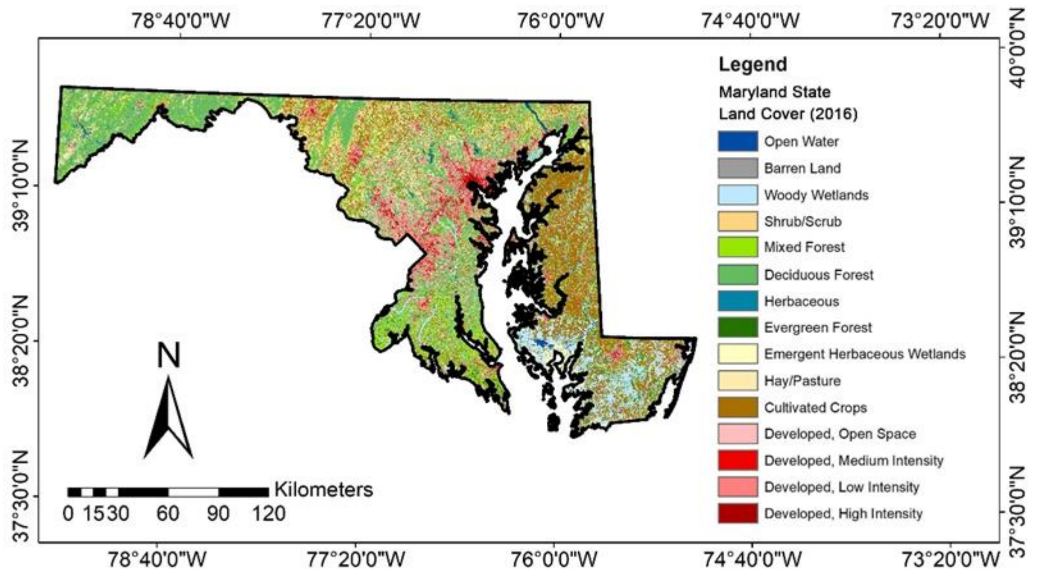

Figure 3. Maryland (USA) land cover map for 2016 (37°53′ N to 39°43′ N; 75°03′ W to 79°29′ W) (derived from MRLC [17]).

Maryland's deciduous forest cover was reduced between 2001 and 2016 (Table 6), which likely indicates there is a reduction in carbon sequestration associated with forests. Our study identified reductions in emergent herbaceous wetlands (−8.9% area change between 2001 and 2016) over the 15-year time period in all soil orders, with the largest losses in the soil order of Spodosols (−76.6% area change between 2001 and 2016; Table 6). It is important to note that the hay or pasture and cultivated landcover classes also became less prevalent (−7.8% area change between 2001 and 2016; Table 6).

3.5. Significance of Results for Maryland's Climate Solutions Now Act

This study scientifically contributes to the overall understanding related to soil CO_2 losses from new land developments regarding net-zero emission targets, which combines land resource and soil data to help identify areas and soils of the highest emissions and soil C sequestration potential in the state of MD. This study provides MD's soil inventory and distribution of soil regulating ES by soil order (Table 5), which is important in determining the maximum potential for C sequestration and soil C storage in the state. Furthermore, this study examines the challenges of meeting net-zero emission goals using the example of CO_2 emissions from land conversions and the potential for removal by soils in MD.

Soil-associated emissions from land developments: Maryland has set a net-zero target by 2045 in the Climate Solutions Now Act, which should also account for emissions from land conversions. This study shows that land conversions have been a significant source of CO_2 emissions in MD based on the land cover change between 2001 and 2016, causing a complete loss of 2.2×10^9 kg of total soil carbon (TSC) which has resulted in \$383.8M (where M = million) of "realized" social costs of CO_2 (SC-CO_2) emissions. Most developments were in the category of medium intensity and generated a loss of 8.3×10^8 kg of TSC with associated \$140.1M in SC-CO_2 (Table 7). Most of TSC's losses and social costs were linked to Ultisols and Alfisols (Table 7). Ultisols are the dominant soil order in MD occupying 64% of the state's area (Table 5). Alfisols are agriculturally important soils.

Table 7. Complete loss of total soil carbon (TSC) and the corresponding maximum potential realized social costs of carbon due from developed land for Maryland, USA, between 2001 and 2016.

NLCD Land Cover Classes (LULC), Developed Area Increase between 2001 and 2016 (km^2), Complete Loss of Total Soil Carbon (kg), SC-CO_2 (\$ = USD)	Degree of Weathering and Soil Development					
	Slight			Moderate	Strong	
	Entisols	Inceptisols	Histosols	Alfisols	Spodosols	Ultisols
	Developed Area Increase between 2001 and 2016 (km^2) Complete Loss of Total Soil Carbon (kg) SC-CO_2 (\$ = USD)					
Developed, open space 58.6 km^2 (6.6×10^8 kg C) \$85.3M	-	5.4 7.6×10^7 \$12.8M	-	10.5 1.2×10^8 \$20.9M	0.3 3.9×10^6 \$665973.0	42.4 3.0×10^8 \$50.9M
Developed, medium intensity 89.4 km^2 (8.3×10^8 kg C) \$140.1M	11.8 1.5×10^8 \$25.6M	5.1 7.1×10^7 \$12.1M	0.2 2.9×10^7 \$5.6M	12.5 1.5×10^8 \$24.8M	0.2 2.6×10^6 \$425754.0	59.6 4.2×10^8 \$71.5M
Developed, low intensity 70.1 km^2 (6.0×10^8 kg C) \$101.9M	3.4 4.4×10^7 \$7.5M	4.5 6.3×10^7 \$10.6M	-	11.5 1.4×10^8 \$22.9M	0.1 1.3×10^6 \$285137.9	50.5 3.6×10^8 \$60.6M
Developed, high intensity 30.3 km^2 (2.9×10^8 kg C) \$49.5M	4.9 6.3×10^7 \$10.7M	1.5 2.1×10^7 \$3.4M	0.1 1.4×10^7 \$2.9M	4.7 5.5×10^7 \$9.4M	0.1 1.3×10^6 \$208971.0	18.9 1.3×10^8 \$22.7M
Totals **248.4 km^2 (2.4×10^9 kg C)** **\$376.7M**	**20.1** **2.6×10^8** **\$43.8M**	**16.5** **2.3×10^8** **\$38.9M**	**0.3** **4.3×10^7** **\$8.5M**	**39.2** **4.6×10^8** **\$78.0M**	**0.7** **9.0×10^6** **\$1.6M**	**171.4** **1.2×10^9** **\$205.7M**

Note: Entisols, Inceptisols, Alfisols, Spodosols, and Ultisols are considered mineral soils. Histosols are mainly organic soils.

All MD's counties experienced increases in developed land areas and associated social costs of C emissions, with Prince George's (\$46.6M), Frederick (\$42.5M), and Anne Arundel (\$35.8M) generating the highest SC-CO_2 costs (Table 8, Figure 4). Developments affected the soil orders of Entisols, Inceptisols, Alfisols, and Ultisols (Table 8). In Anne Arundel County, however, development impacted the soil order Histosols (Table 8), which often are protected from development in state and national jurisdictions. Histosols are C-rich soils, which are often associated with wetlands. The spatial distribution of emissions and associated social costs is often associated with existing urban developments (Figure 4). Sexton et al. (2013) [13] analyzed urban growth using levels of estimated impervious cover for the Washington, D.C. and Baltimore, MD areas.

Table 8. Land development increases (landcover category: developed open space, developed medium intensity, developed low intensity, and developed high intensity), complete loss of total soil carbon (TSC) with the corresponding maximum potential realized social costs of carbon for newly developed land by county and soil order in Maryland, USA, between 2001 to 2016.

County/City	Total Area Change (km^2), ($SC\text{-}CO_2$, $ = USD), Loss of TSC (kg)	Degree of Weathering and Soil Development					
		Slight			Moderate	Strong	
		Entisols	Inceptisols	Histosols	Alfisols	Spodosols	Ultisols
		Developed Area Increase between 2001 and 2016 (km^2) Complete Loss of Total Soil Carbon (kg)					
Allegany	2.6 ($4.7M) 2.7×10^7	0.3 3.8×10^6	1.0 1.4×10^7	0 0	0.1 1.2×10^6	0 0	1.1 7.8×10^6
Anne Arundel	22.5 ($35.8M) 2.1×10^8	1.3 1.7×10^7	0.5 7.0×10^6	0.3 4.3×10^7	0.1 1.2×10^6	0 0	20.3 1.4×10^8
Baltimore City	2.1 ($3.9M) 2.2×10^7	0.9 1.2×10^7	0.1 1.4×10^6	0 0	0.4 4.7×10^6	0 0	0.6 4.3×10^6
Baltimore	14.1 ($23.9M) 1.4×10^8	5.0 6.4×10^7	0.8 1.1×10^7	0 0	1.1 1.3×10^7	0 0	7.3 5.2×10^7
Calvert	5.4 ($10.3M) 5.8×10^7	0.4 5.1×10^6	2.4 3.4×10^7	0 0	0.1 1.2×10^6	0 0	2.5 1.8×10^7
Caroline	1.2 ($1.6M) 9.8×10^6	0.1 1.3×10^6	0.1 1.4×10^6	0 0	0 0	0 0	1.0 7.1×10^6
Carroll	8.8 ($12.7M) 7.5×10^7	0.6 7.7×10^6	0.5 7.0×10^6	0 0	1.1 1.3×10^7	0 0	6.6 4.7×10^7
Cecil	12.2 ($16.5M) 9.8×10^7	1.1 1.4×10^7	0.1 1.4×10^6	0 0	0.9 1.1×10^7	0 0	10.1 7.2×10^7
Charles	16.6 ($23.6M) 1.4×10^8	3.4 4.4×10^7	0.3 4.2×10^6	0 0	0 0	0 0	12.9 9.2×10^7
Dorchester	2.5 ($3.4M) 2.0×10^7	0.3 3.8×10^6	0.1 1.4×10^6	0 0	0 0	0 0	2.1 1.5×10^7
Frederick	22.6 ($42.5M) 2.5×10^8	0.3 3.8×10^6	2.0 2.8×10^7	0 0	16.1 1.9×10^8	0 0	4.2 3.0×10^7
Garrett	3.2 ($5.7M) 3.4×10^7	0.1 1.3×10^6	1.2 1.7×10^7	0 0	0.2 2.4×10^6	0.2 2.6×10^6	1.5 1.1×10^7
Harford	13.1 ($20.2M) 1.2×10^8	0.1 1.3×10^6	2.0 2.8×10^7	0 0	2.7 3.2×10^7	0 0	8.3 5.9×10^7
Howard	17.3 ($25.3M) 1.5×10^8	0.6 7.7×10^6	2.4 3.4×10^7	0 0	1.4 1.7×10^7	0 0	12.9 9.2×10^7
Kent	1.4 ($1.7M) 9.9×10^6	0 0	0 0	0 0	0 0	0 0	1.4 9.9×10^6
Montgomery	24.5 ($31.6M) 1.9×10^8	1.0 1.3×10^7	0.6 8.4×10^6	0 0	0.6 7.1×10^6	0 0	22.3 1.6×10^8
Prince George's	35.6 ($46.6M) 2.8×10^8	2.8 3.6×10^7	0.9 1.3×10^7	0 0	0.2 2.4×10^6	0 0	31.7 2.3×10^8
Queen Anne's	5.1 ($7.0M) 4.0×10^7	0.2 2.6×10^6	0.4 5.6×10^6	0 0	0 0	0 0	4.5 3.2×10^7
Somerset	1.4 ($2.1M) 1.2×10^7	0.3 3.8×10^6	0 0	0 0	0 0	0 0	1.1 7.8×10^6
St. Mary's	8.4 ($10.8M) 6.4×10^7	0.5 6.4×10^6	0.2 2.8×10^6	0 0	0 0	0 0	7.7 5.5×10^7
Talbot	3.0 ($3.7M) 2.1×10^7	0 0	0 0	0 0	0 0	0 0	3.0 2.1×10^7
Washington	16.0 ($31.3M) 1.9×10^8	0.1 1.3×10^6	0.5 7.0×10^6	0 0	14.5 1.2×10^6	0 0	0.9 6.4×10^6
Wicomico	6.7 ($11.4M) 6.7×10^7	2.9 3.7×10^7	0.4 5.6×10^6	0 0	0 0	0.1 1.3×10^6	3.3 2.3×10^7
Worcester	5.6 ($7.8M) 1.3×10^7	0.6 7.7×10^6	0 0	0 0	0 0	0.1 1.3×10^6	0.5 3.6×10^6
Totals	**252.0 ($383.8M)** $\mathbf{2.2 \times 10^9}$	**23.0 ($50.0M)** $\mathbf{2.9 \times 10^8}$	**16.5 ($39.0M)** $\mathbf{2.3 \times 10^8}$	**0.3 ($8.5M)** $\mathbf{4.3 \times 10^7}$	**39.5 ($78.5M)** $\mathbf{5.7 \times 10^8}$	**0.4 ($1.6M)** $\mathbf{5.2 \times 10^6}$	**171.9 ($206.3M)** $\mathbf{1.2 \times 10^9}$

Note: Entisols, Inceptisols, Alfisols, Spodosols, and Ultisols are mineral soils. Histosols are mostly organic soils. M = million = 10^6.

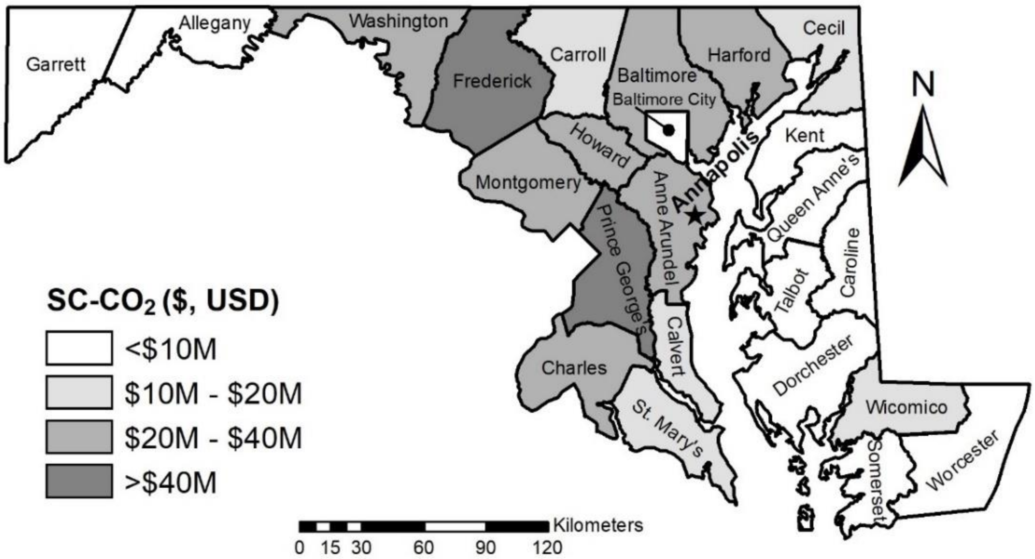

Figure 4. Realized monetary value for the mid-point total soil carbon (TSC) estimate for newly "developed" land cover areas (open space, low, medium, and high intensity) between 2001 and 2016 for Maryland (USA) using a social cost of carbon (SC-CO_2) of $46 per metric ton of CO_2 applicable until the year of 2025 (using 2007 U.S. dollars with an average discount rate of 3% [14]).

Potential for soil-associated removal of emissions as a result of land developments: There are many limitations with the potential for soil-associated removal of emissions from land development in MD. One limitation is that MD's soils are naturally very limited in the potential for additional C sequestration because the most common soil order, Ultisols (64% of the state's area), are highly weathered and low-fertility soils (Table 5). Other soils are slightly weathered soils (23% of the state's area), which also have limited capacity to sequester C. Moderately weathered Alfisols, which cover 12% of the state's area, are agriculturally important, limiting additional C sequestration as well.

A second limitation is that conversions to developed land reduce the availability of land and soils for C sequestration. Maryland's developments were at the expense of NLCD land cover classes that aid in GHG sequestration, which include shrub/scrub (−22.2%), deciduous forest (−2.8%), emergent herbaceous wetlands (−8.9%), and hay/pasture (−7.8%) (Table 6). According to Petrie et al. (2014) [22], shrub/scrub land is capable to sequester 49 g C m^{-2} $year^{-1}$. Developments are often accompanied by an increase in impervious surface cover [13]. Sexton et al. (2013) [13] reported an average annual gain in the impervious surface cover of 11 ± 2 km^2 $year^{-1}$ in the Washington, D.C., and Baltimore, MD area.

A third limitation is associated with the soil type and land cover intersection (Table 9) which indicates few possibilities for additional plant and soil-based C sequestration. There is little available land for forest planting to sequester C because the herbaceous and barren land, as well as the shrub/scrub landcover categories, when totaled, only cover 1.5% of the total land area. Converting areas from agricultural to forestry land use reduces the food provisioning ecosystem services potential.

A fourth limitation is associated with potential land and soil loss because of future sea-level rise in MD, which may impact 17 of MD's 23 counties, with Dorchester, Wicomico, and Queen Anne's counties experiencing the most dramatic land losses (Figure 5, Table 10). These losses will generate additional social costs because of migration, costs of relocation, and damage to infrastructure. Relocation within the state will be limited because of a high amount of private land ownership (92.4%) [11] and a low proportion of public lands.

Table 9. Land use/land cover (LULC) by soil order in Maryland (USA) in 2016.

NLCD Land Cover Classes (LULC)	2016 Total Area by LULC (%)	Degree of Weathering and Soil Development					
		Slight			Moderate	Strong	
		Entisols	Inceptisols	Histosols	Alfisols	Spodosols	Ultisols
		2016 Area by Soil Order, % from Total Area in Each LULC					
Barren land	0.3	43.1	9.7	0.0	5.6	0.8	40.8
Woody wetlands	10.9	10.8	15.4	5.2	4.4	4.5	59.7
Shrub/Scrub	0.7	8.0	15.6	0.0	5.5	1.1	69.8
Mixed forest	9.8	5.5	19.6	0.0	11.2	0.5	63.2
Deciduous forest	23.5	3.3	25.9	0.0	8.3	0.8	61.6
Herbaceous	0.5	9.6	17.3	0.2	7.0	1.2	64.8
Evergreen forest	2.6	12.3	9.7	0.0	4.3	2.2	71.5
Emergent herbaceous wetlands	3.2	13.8	2.2	19.5	50.1	0.1	14.3
Hay/Pasture	10.7	2.5	16.2	0.0	25.1	0.1	56.1
Cultivated crops	21.1	4.6	6.5	0.0	11.8	1.0	76.1
Developed, open space	9.4	7.3	10.8	0.1	10.5	0.4	70.9
Developed, medium intensity	2.0	26.3	4.8	0.1	11.0	0.1	57.7
Developed, low intensity	4.8	11.7	7.2	0.1	14.2	0.1	66.6
Developed, high intensity	0.6	39.6	3.7	0.1	10.0	0.1	46.5

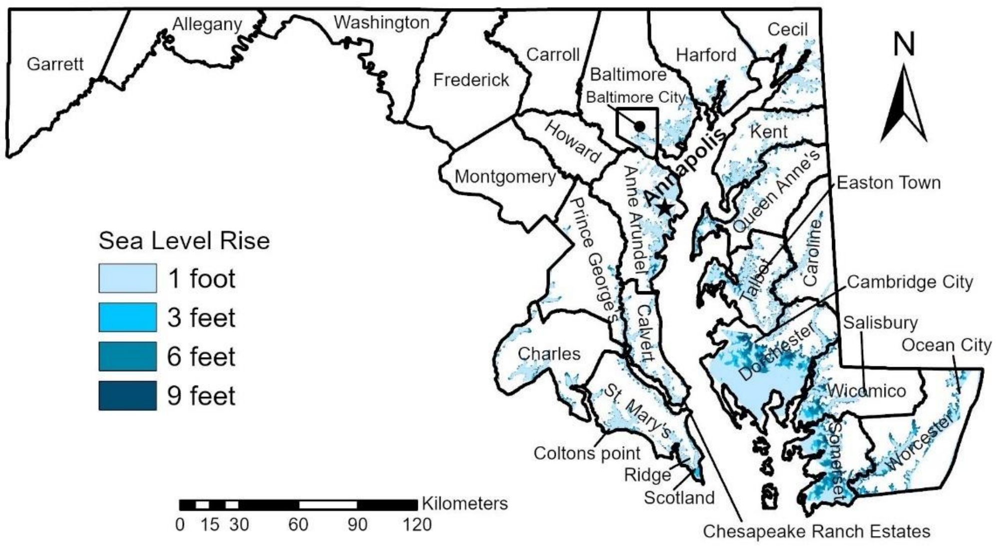

Figure 5. Projections of possible, future, sea level rise associated with climate change in Maryland (USA), which may have an impact on 17 out of 23 Maryland's counties with Dorchester, Wicomico, and Queen Anne's counties experiencing the most dramatic land losses.

3.6. Importance of Results

3.6.1. The Role of Net-Zero Goals in Addressing Climate Change

Maryland's net-zero targets are an important contribution to the net-zero goals set worldwide (Net-zero Tracker [24]) and should be viewed in the broader context of climate change planning. The results of the study will be discussed using a list of attributes associated with credible net-zero targets and practices reported by Fankhauser et al., 2021 [1]:

Table 10. Potential loss of county area (%) from sea level rise in Maryland, USA (from an original spatial analysis of data provided by the National Oceanic and Atmospheric Administration (NOAA) [23]).

County (Affected by Sea Level Rise)	County Area Loss Due to Sea Level Rise (%)			
	1 Foot	3 Feet	6 Feet	9 Feet
Anne Arundel	8.8	9.9	11.7	14.4
Baltimore	3.0	3.6	4.3	5.2
Baltimore City	11.4	11.6	12.5	15.3
Calvert	5.4	6.9	8.1	9.3
Caroline	3.3	3.8	4.4	5.3
Cecil	6.8	7.4	8.1	9.0
Charles	4.9	5.9	7.1	8.5
Dorchester	40.9	55.1	63.8	69.0
Harford	2.1	2.4	2.7	2.9
Howard	11.6	14.1	17.1	19.9
Kent	4.2	4.8	5.4	5.9
Prince George's	5.4	6.6	8.4	10.7
Queen Anne's	23.9	36.2	47.1	51.7
Somerset	9.6	11.7	15.0	18.6
St. Mary's	14.7	16.7	22.6	30.8
Talbot	8.6	12.8	17.5	22.2
Wicomico	40.1	44.9	52.8	60.7

- **Front-loaded emission reductions:** To stay below the maximum temperature increase goal of 1.5 °C, emissions must be reduced as soon as possible. Recommendations include short-term emission-reduction targets that define long-term net-zero commitments. In the case of MD, the state should determine permissible levels of soil-associated emissions caused by land conversions depending on the state's comprehensive net-zero emissions plan.

- **Comprehensive approach to emission reductions:** Efforts in certain sectors, such as energy and automotive, have been successful, but net-zero requires all sectors to have zero-carbon solutions, including heavy industries, buildings, aviation, mining, and agriculture. Currently, soil-associated emissions from land developments are not included in MD's carbon footprint, which will have an impact on the state's net-zero targets.

- **Cautious use of carbon dioxide removal:** Methods of removing CO_2 can be constrained by geopolitical factors and cost considerations and may be limited by technological, biological, and institutional factors. Nature-based solutions may involve fewer trade-offs and be more resilient. The potential for soil-associated removal of emissions from land conversions in Maryland is very limited due to various factors including inherent soil limitations, sea-level rise, and other factors.

- **Effective regulation of carbon offsets:** Net-zero requires the balancing between emission sources and sinks. The sinks of carbon removal require long-term, multi-decadal storage to effectively regulate atmospheric GHG. This study demonstrated the use of remote sensing and geospatial analysis in detecting soil-associated emissions from land conversions, which can be used to regulate the sources and sinks of emissions. For example, MD can impose fees on soil-associated emissions linked to land developments to offset the state's social costs of emissions and their damages.

- **An equitable transition to net-zero:** Climate action requires fairness among all individuals and groups. The challenge of meeting net-zero should be shared across all stakeholders. This study identified the importance of considering soil diversity (pedodiversity) in such a transition. Maryland's inherent soil diversity within the state and its counties is highly variable and has a direct impact on the variability of soil-associated emissions from land developments.

- **Alignment with broader socio-ecological solutions:** Most socio-ecological problems are interlinked, with climate change multiplying the negative effects. Net-zero plans should acknowledge broader environmental challenges and seek to achieve solutions for multiple challenges. This study quantified the soil-associated emissions from land developments based on both physical quantity and the monetary value of the social costs of C. Net-zero emissions concepts can be broadened to include net-zero emissions social costs. Physical removal of emissions from the atmosphere does not solve the problem of emissions social costs, which are associated with damage to society.

- **Pursuit of new economic opportunities:** Net-zero policies can provide economic opportunities. Addressing these opportunities is significant in transitioning from high-emission practices and may require collaboration between the government, local communities, and industry, investment in social protection, education, and related skills. This study shows physical emissions and related social costs associated with land conversions. A cost-benefit analysis could include both the economic benefits of development along with the emission-based long-term social costs and other damages linked to climate change (e.g., sea level rise). Development that favors formerly developed areas or at a higher density could reduce the emission and social costs associated with soil-associated emissions as a result of land development.

Our study reveals a **limitation of the net-zero goals regarding soil and land resources:** Soil-associated emissions from the identified new land development can be represented both as the physical quantity of CO_2 released to the atmosphere and as a social cost of these releases. For example, in the case of MD, the physical quantity of C released was 2.2×10^9 kg of total soil carbon (TSC) which represents a social cost of $383.8M based on a set value from the US EPA. It is possible to obtain the net-zero goal, in the case of soil-associated emissions, through CO_2 removal or sequestration, but this will not necessarily reduce the damages caused by these and earlier emissions. Therefore net-zero carbon emissions will not equal net-zero damages from these emissions. In the case of MD, the $383.8M social cost associated with physical emissions would not cover even a fraction of the costs from ongoing and future climate change impacts in the state (e.g., sea level rise). The future loss of coastal real estate, as well as relocation and other costs, are market-driven and will far surpass the calculated social cost of these soil-associated emissions, which are calculated as a fixed quantity.

3.6.2. The Legal Aspects of the Net-Zero Goals

Benefits of net-zero goals

Across the world, net-zero pledges have become increasingly common, but with different levels of commitment [25]. However, the adoption of a net-zero pledge does not necessarily mean that the committed party (e.g., country, state, organization, business, etc.) has any working plans to fulfill these pledges [25]. Very often, these pledges are just a starting point for tracking and reducing these emissions [25].

Maryland's net-zero pledges, part of its Climate Solutions Now Act, are a substantial environmental win for Maryland, establishing Maryland as a national leader in fighting climate change (Table 11). The overall plan (Table 11) includes an interim first target but does not detail a mechanism for accountability if the plan is not met. Furthermore, the plan (Table 11) does not attempt to address historical emissions and focuses on future nature-based removals of GHG, even though this potential is severely restricted by the availability of land (particularly in the face of sea level rise) and the limited capacity of MD's soil resources to store additional C with their highly weathered status.

Table 11. Net-zero tracker report for the state of Maryland retrieved on 17 October 2022 [24].

Key Categories	Details
Targets	**Status**: in law **Interim first target**: 2031 **Interim target type**: reduction of emissions
Coverage	**Greenhouse gases**: not provided **Consumption emissions**: yes **Historical emissions**: no **All territorial emissions**: not provided
Governance	**Plan detail level**: incomplete **Includes reporting on an annual basis**: yes **Includes equity**: yes **Formal mechanisms for accountability**: not provided
Offsets and Sinks	**Includes plans to utilize external offset credits:** no **Details separate emission targets for removals and reductions:** no **Includes conditions to utilize offset credits:** no **Plans for carbon dioxide removal (CDR):** nature-based removals

Maryland is one of only five states with net-zero targets [26]. This is especially important because Maryland is vulnerable to climate change: Maryland has over 3100 miles of coastline, making the state one of the most exposed to the dangers of rising sea levels [27]. Maryland's net-zero pledge demonstrates the state's commitment to working to ameliorate climate change, especially because it requires the state to achieve net-zero relatively quickly by 2045. Even if the pledge does not cure climate change in Maryland, it is certainly an important step in the right direction. The net-zero pledge may lead Maryland—and other states—to take important immediate measures. For example, the statute that contains Maryland's net-zero pledge also contains requirements for relatively quick emissions reductions from large buildings and state passenger vehicles [26].

Limitations of net-zero goals

However, the results that net-zero pledges eventually produce may prove disappointing. Indeed, net-zero pledges can impede progress on climate change rather than promote it. It is costly for a country to do anything substantial to reduce climate change now. Large amounts will need to be spent on alternative energy sources that produce less GHG; oil, coal, and natural gas are relatively cheap compared to wind and solar. There will be large societal costs to countries that force a transition away from cheap fossil fuels. A forced transition will cause suffering as energy prices rise, and the population, especially the vulnerable parts of it, must make do with less. As energy prices rise dramatically, social unrest might occur, as in the past.

Leaders who impose clean-energy transitions also bear large political costs. People may generally favor the goal of reducing GHG emissions to limit climate change. However, voters often recoil when they must pay the large costs. Politicians who preside over such periods of rising prices are often blamed and not reelected.

In contrast, net-zero pledges sound impressive. They allow politicians and the people they represent to proclaim that they are taking strong action, not just reducing emissions but reducing them all the way to zero. Politicians can sell themselves as environmental heroes to voters. In addition, countries, and parts of countries, such as the U.S. states, can market themselves as dedicated environmental champions to national and international communities.

Such promises have little or no present cost. A promise such as that of Maryland to be net-zero by 2045 requires the state to do nothing now; the requirement is only that Maryland has done a lot by 2045. Maryland's net-zero "commitment" does include an interim target of emissions reductions by 2031 [24]. But this interim target is weak and full of loopholes, requiring no absolute reduction and not addressing other sources of GHGs [24]. Moreover, there is no way to enforce even these porous aspirations. Suppose that 2031 approaches and Maryland has not achieved its interim target. Or suppose that 2045 approaches and Maryland are not even close to achieving the ultimate net-zero goal.

The Maryland legislature can simply pass legislation to postpone or eliminate the goal. If achieving the interim goal would require substantial hardship for the state's inhabitants, then there is an overwhelming incentive for politicians to attempt to appease voters and eliminate the requirements. Even if Maryland's net-zero pledge remains in force and is not eliminated by the state's legislature, the pledge will not enforce itself. For the state to achieve the goals for 2031 and 2045, the state will need to create much new legislation and regulation. The new rules will need to be restrictive and impose large costs—costs that most entities have been unwilling to bear. As a leading Maryland lawyer notes, "There are no low-hanging fruits on the tree of greenhouse gas reduction" [28]. If Maryland retained its net-zero pledge but failed to take the actions necessary to achieve the pledge, it is possible, but not certain, that a citizen or interest group could sue the state to force compliance—although this is a difficult issue of administrative law. However, the state could always avoid the need to comply with its pledge simply by enacting legislation to eliminate the pledge.

Although there are a few exceptional countries such as Sweden [25], most people in other areas tend to be unwilling to make substantial current sacrifices to combat climate change. Their behavior in failing to take strong current action indicates that they are unwilling to incur substantial costs in the present to reduce global warming, even though inaction promises to impose the large costs of climate change on future generations. Although people may profess concern for the world that they will bequeath to their children and grandchildren, their conduct suggests otherwise. The only response of many countries to the dangers of GHG emissions is not resolute action but, instead, the cost-free, unenforceable promise of a net-zero plan.

Net-zero resolutions are a perfect example of words that are currently cost-free, and will probably remain cost-free for decades, if not forever. Any costs that are imposed can be delayed so that only later generations will bear them. Current politicians will be long gone by the time net-zero promises must be kept, many decades from now. And later generations can themselves postpone the attainment of the goals, continually kicking the can down the generational road, even as the world roasts and the seas rise.

In addition, countries' voluntary achievement of their net-zero pledges is unlikely because it is a so-called "prisoner's dilemma": each country, state, or other political entity has the incentive to hold back from incurring the costs of GHG reduction, instead hoping that other countries will bear the costs [29]. That is, each political entity has the incentive to free-ride on the efforts of other entities, emitting nothing but empty words of environmentalist jargon without being willing to incur costs. However, because every political unit has this incentive to free ride and should recognize that others have this same incentive, a dangerous equilibrium will exist in which few, if any, countries or political entities will incur costs to prevent climate change.

Recent experience confirms that countries routinely ignore their climate pledges. For example, at the Glasgow climate summit in 2021, 193 countries pledged to take various environmental actions by the next year. However, at the deadline, only 26 had complied—leading to predictions that the world would, by the end of the century, suffer catastrophic global warming [30,31].

Because net-zero pledges are cheap talk that imposes no enforceable costs, countries and other political entities are eager to have them–especially if the pledges are weak and vague with any possible costs delayed for many decades. Accordingly, a recent deluge of net-zero pledges has increased the number of countries with such targets to more than 135 [25]. But so many countries are willing to establish net-zero targets because they are cost-free but provide political benefits: without the countries' actually doing anything, a country can enjoy the public-relations benefits of seeming to be an environmental champion. For example, under Maryland's net-zero pledge, Maryland need not achieve any concrete target until its interim target in 2031 and need not achieve net-zero until 2045.

Indeed, the net-zero pledges may harm the environment. A worthless net-zero pledge that requires no current action can sometimes replace effective measures that the state might otherwise take [5]. A political unit's net-zero pledge is especially cost-free if the target time for completion is far in the future, or if the pledge's requirements are vague. Maryland's net-zero pledge is more aggressive than some others. And Maryland is certainly more committed to controlling climate change than the many states that lack a net-zero pledge [24]. Its target year of 2045 is relatively soon; in comparison, the target date for the U.S. is 2050, and for India, it is 2070 [24]. However, Maryland's first interim target is not until 2031. Its plan is vague, with many details unspecified. Moreover, Maryland's net-zero plan, like those in other jurisdictions, ignores GHG emissions from soil disturbance. So even if Maryland achieved net-zero according to its calculations, because its calculations ignore the GHGs from soil disturbance, the state would not achieve true net-zero. Finally, because so much of Maryland's land (92.4%) [11] is owned privately, it would be difficult to coordinate changes in land use to reduce net emissions. The information in this paper might be able to be used by environmental interest groups to sue Maryland to force it to consider GHG releases from soil disturbance in calculating whether it is on track to achieve the required levels in 2031 and 2045.

Refining net-zero goals

An essential aspect of a net-zero pledge is that it does not even begin to require a state or other entity to eliminate emissions' social costs. As already discussed, past GHG emissions have imposed substantial costs on Maryland, and the emissions will continue to impose costs until net-zero is achieved in 2045—or even longer if Maryland's net-zero pledge is not enforced as scheduled.

So even if the state achieved net-zero emissions in 2045, it would not in that year achieve net-zero social costs; although no new social costs from emissions would be incurred from that year on, the sum of the past social costs would still be far above zero. To achieve net-zero social costs, either (1) there would need to be many more years of net negative emissions, where more GHG is removed than is added, or (2) the state would need to raise taxes to pay for the breathtakingly large sums that would be necessary to balance the large social environmental costs that have already been incurred. Our study proposes to add net-zero social cost to the overall concept of net-zero emissions (Table 12). While the concept of net-zero emissions deals with present-day reduction and physical removal of GHG emissions, it does not address the social cost of damages to the society and environment from past emissions. The goal of adding net-zero social cost may help define future climate action to address climate change impacts using equitable and market-based mechanisms.

Table 12. The newly proposed addition of net-zero social costs to the concept of net-zero emissions.

Net-Zero Emissions and Social Costs		
Net-Zero Emissions	**+**	**Net-Zero Social Costs**
Units: kg of emissions		**Units**: Monetary value (e.g., $ = USD)
Advantages		
1. Reduction in physical emissions from various sources to net-zero.		1. Equitable and market-based allocation of financial resources for social costs of climate change compensation.
2. Removal of current emitted emissions.		2. Equitable and market-based investment to reduce social costs beyond the emissions reductions.
Limitations		
1. Disregards damages to the society and environment.		1. Requires significant financial resources from the public and private sectors.
2. Disregards historical emissions and damages.		2. Cross-boundary challenges.
3. Not all sources of emissions are included. Removal may not be possible.		3. Assuming fixed social costs of emissions will likely undervalue the true costs of climate change.

Climate change impacts and biodiversity losses are often linked together. The state of MD supports global climate change efforts with its net-zero emissions plan and goals. Biodiversity losses are often considered separately from climate change as was pointed out by participants in the 2022 United Nations (UN) Biodiversity Conference [32]. As part of this effort, many countries committed to preserving 30 percent of the land, water resources, and oceans. The United States (US) is one of two entities that are not a signature to this UN Convention on Biological Diversity [32]. However, the US has its own biodiversity preservation initiative (30 × 30) which is intended to protect 30% of land and 30% of water resources for the country by 2030 [33]. Currently, approximately 12% of US lands are protected [34]. It is unclear if soil diversity (pedodiversity) is part of the preservation goals at the local and US level, however, it is clear that land development and future sea level rise have and will impact the ability to achieve these large conservation goals. Criteria for US preservation priorities are just now being developed [34] and could use measures of pedodiversity which should be considered a part of biodiversity. Our study demonstrates that it is possible to track the impact of land cover change on land loss. This pedodiversity is likely a critical component of supporting and preserving both biodiversity and water resources. This study found development, over time, reduces the capacity and future potential of soil resources to store C, and the same development pressures reduce soil resources available to support plant and animal diversity. These biodiversity initiatives should be linked to climate change goals, such as net-zero, to help prioritize land development decisions within the state of MD and beyond.

4. Conclusions

The present study hypothesizes that the soil-associated emissions from land conversions should be included in the net-zero target calculations. Our study used new soil-associated emission estimates related to prior land conversions between 2001 and 2016 for the state of MD determined using a soil spatial data analysis that integrated remote sensing to quantify soil contributions to the net-zero target. Our study demonstrated how GHG emissions calculated from spatially explicit scientific data can be used to quantify the amount of C, which needs to be removed as well as its social costs of CO_2 (SC-CO_2) emissions monetary value. Current MD's GHG inventory does not identify soil as a potential GHG emissions source. Our results show that the state of MD does not have net-zero emissions in areas associated with land development. The state has experienced landcover changes with a complete loss of 2.2×10^9 kg of total soil carbon (TSC), which resulted in $383.8M in "realized" social costs of CO_2 emissions, principally linked to the Ultisols soil order (1.2×10^9 kg of TSC loss, $206.3M SC-$CO_2$). The counties that had the most development activity were Prince George's (2.8×10^8 kg of TSC loss, $46.6M), Frederick ($2.5 \times 10^8$ kg of TSC loss, $42.5M), and Anne Arundel (2.1×10^8 kg of TSC loss, $35.8M) counties.

In the final analysis, the net-zero approach may be relatively unproductive. The target dates and interim dates are so far in the future that an administrative unit can simultaneously have a net-zero plan but do little if anything now. Moreover, when the plan's deadlines for action finally approach, the administrative unit (e.g., country, state, etc.) can simply delay the target dates for additional decades. Indeed, the net-zero approach may sometimes deter actual substantive change. A political entity's toothless net-zero pledge can replace any need for the administrative unit (e.g., country, etc.) to actually take concrete action. Our study proposes to add the net-zero social cost concept to the net-zero emissions concept. While the net-zero emissions concept deals with present-day reduction and physical removal of GHG emissions, it does not address the social cost of damages to society and the environment from past emissions. The goal of adding net-zero social cost may help define future climate action to address climate change impacts using equitable and market-based mechanisms. Future research could examine the projected social costs associated with climate change to determine the gap between the fixed social cost of GHG emissions and the market-based projected loss and damage. For example, coastal areas of

Maryland have a high predicted loss and damage from projected sea level rise, which, if considered, could greatly increase the mitigation cost.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/geographies3010003/s1, Table S1: Midpoint soil organic carbon (SOC) storage and its monetary value by soil order and county for the state of Maryland (USA), based on the areas shown in Table 3 and the area-normalized mid-point monetary values in Table 4; Table S2: Midpoint soil organic carbon (SIC) storage and its monetary value by soil order and county for the state of Maryland (USA), based on the areas shown in Table 3 and the area-normalized midpoint monetary values in Table 4; Table S3: Midpoint total soil carbon (TSC) storage and its monetary value by soil order and county for the state of Maryland (USA), based on the areas shown in Table 3 and the area-normalized midpoint monetary values in Table 4.

Author Contributions: Conceptualization, E.A.M.; methodology, E.A.M., M.A.S. and H.A.Z.; formal analysis, E.A.M. and P.C.H.; writing—original draft preparation, E.A.M.; writing—review and editing, E.A.M., C.J.P., G.B.S. and M.A.S.; visualization, H.A.Z., L.L. and Z.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: We would like to thank the reviewers for their constructive comments and suggestions.

Conflicts of Interest: The authors declare no conflict of interest.

Glossary

CF	Carbon footprint
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
STATSGO	State Soil Geographic Database
TSC	Total soil carbon
USDA	United States Department of Agriculture

References

1. Fankhauser, S.; Smith, S.M.; Allen, M.; Axelsson, K.; Hale, T.; Hepburn, C.; Kendall, J.M.; Radhika Khosla, R.; Lezaun, J.; Mitchell-Larson, E.; et al. The meaning of net-zero and how to get it right. *Nat. Clim. Change* **2022**, *12*, 15–21. [CrossRef]
2. Loveday, J.; Morrison, G.M.; Martin, D.A. Identifying knowledge and process gaps from a systematic literature review of net-zero definitions. *Sustainability* **2022**, *14*, 3057. [CrossRef]
3. Organisation for Economic Co-operation and Development (OECD). Understanding Countries' Net-Zero Emissions Targets. 2021. Available online: https://www.oecd.org/environment/understanding-countries-net-zero-emissions-targets-8d25a20c-en.htm (accessed on 27 October 2022).
4. Mikhailova, E.A.; Lin, L.; Hao, Z.; Zurqani, H.A.; Post, C.J.; Schlautman, M.A.; Post, G.C. Contribution of land cover conversions to Connecticut (USA) carbon footprint. *Geographies* **2022**, *2*, 286–302. [CrossRef]
5. Rogelj, J.; Geden, O.; Cowie, A.; Reisinger, A. Three ways to improve net-zero emissions targets. *Nature* **2021**, *591*, 365–368. [CrossRef]
6. Maryland Senate Bill 528. Climate Solutions Now Act of 2022. Available online: https://mgaleg.maryland.gov/2022RS/bills/sb/sb0528E.pdf (accessed on 1 September 2022).
7. Mikhailova, E.A.; Zurqani, H.A.; Post, C.J.; Schlautman, M.A.; Post, C.J. Soil diversity (pedodiversity) and ecosystem services. *Land* **2021**, *10*, 288. [CrossRef]
8. USDA/NRCS. Sassafras—Maryland State Soil. Available online: https://stmarysscd.com/wp-content/uploads/2015/02/md_soil.pdf (accessed on 1 September 2022).

9. Soil Survey Staff. n.d.a. *Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic 548 (SSURGO) Database*. Available online: https://nrcs.app.box.com/v/soils (accessed on 10 September 2022).
10. The United States Census Bureau. TIGER/Line Boundary Shapefiles. 2018. Available online: https://www.census.gov/geographies/mapping-files/time-series/geo/tiger-line-file.2018.html (accessed on 10 September 2022).
11. U.S. Bureau of the Census. Statistical Abstract of the United States. 1991; p. 201. Available online: https://www.census.gov/library/publications/1991/compendia/statab/111ed.html (accessed on 10 December 2022).
12. Aighewi, I.T.; Nosakhare, O.K.; Ishaque, A.B. Land use-land cover changes and sewage loading in the lower eastern shore watersheds and coastal bays of Maryland: Implications for surface water quality. *J. Coast. Res.* **2013**, *29*, 1073–1082. [CrossRef]
13. Sexton, J.O.; Song, X.; Huang, C.; Channan, S.; Baker, M.E.; Townshend, J.R. Urban growth of the Washington, D.C.-Baltimore, MD metropolitan region from 1984 to 2010 by annual, Landsat-based estimates of impervious cover. *Remote Sens. Environ.* **2013**, *129*, 42–53. [CrossRef]
14. EPA (United States Environmental Protection Agency). The Social Cost of Carbon. EPA Fact Sheet. 2016. Available online: https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html (accessed on 15 August 2022).
15. Guo, Y.; Amundson, R.; Gong, P.; Yu, Q. Quantity and spatial variability of soil carbon in the conterminous United States. *Soil Sci. Soc. Am. J.* **2006**, *70*, 590–600. [CrossRef]
16. Groshans, G.R.; Mikhailova, E.A.; Post, C.J.; Schlautman, M.A.; Zhang, L. Determining the value of soil inorganic carbon stocks in the contiguous United States based on the avoided social cost of carbon emissions. *Resources* **2019**, *8*, 119. [CrossRef]
17. Multi-Resolution Land Characteristics Consortium (MRLC). Available online: https://www.mrlc.gov/ (accessed on 1 March 2022).
18. ESRI (Environmental Systems Research Institute). ArcGIS Pro 2.6. Available online: https://pro.arcgis.com/en/pro-app/2.6/get-started/whats-new-in-arcgis-pro.htm (accessed on 1 March 2022).
19. Mikhailova, E.A.; Groshans, G.R.; Post, C.J.; Schlautman, M.A.; Post, C.J. Valuation of total soil carbon stocks in the contiguous United States based on the avoided social cost of carbon emissions. *Resources* **2019**, *8*, 157. [CrossRef]
20. Mikhailova, E.A.; Groshans, G.R.; Post, C.J.; Schlautman, M.A.; Post, G.C. Valuation of soil organic carbon stocks in the contiguous United States based on the avoided social cost of carbon emissions. *Resources* **2019**, *8*, 153. [CrossRef]
21. Soil Survey Staff. Natural Resources Conservation Service, United States Department of Agriculture. Photos of Soil Orders. Available online: https://www.nrcs.usda.gov/resources/education-and-teaching-materials/the-twelve-orders-of-soil-taxonomy (accessed on 20 September 2022).
22. Petrie, M.D.; Collins, S.L.; Swann, A.M.; Ford, P.L.; Litvak, M.E. Grassland to shrubland state transitions enhance carbon sequestration in the northern Chihuahuan Desert. *Glob. Change Biol.* **2014**, *21*, 1226–1235. [CrossRef]
23. National Oceanic and Atmospheric Administration (NOAA). Climate.gov. Available online: https://www.climate.gov/maps-data (accessed on 2 October 2022).
24. Net-zero Tracker. 2022. Available online: https://zerotracker.net/ (accessed on 19 October 2022).
25. Nugent, C. The World's Top Carbon Emitters Now All Have Net-Zero Pledges. Most of Them Are Too Vague. *Time* 2021. Available online: https://time.com/6113845/net-zero-climate-pledge-impact/ (accessed on 27 October 2022).
26. National Caucus of Environmental Legislators (NCEL), Maryland Passes the Climate Solutions Now Act. 11 April 2022. Available online: https://www.ncelenviro.org/articles/maryland-passes-the-climate-solutions-now-act/ (accessed on 27 October 2022).
27. Neumann, J. Climate Solutions Now Act: What's in the New Law? Environment Maryland. 19 April 2022. Available online: https://environmentamerica.org/maryland/articles/climate-solutions-now-act-whats-new-law/ (accessed on 27 October 2022).
28. Powell, M. The Climate Solutions Now Act of 2022, Gordon-Feinblatt Legal Bulletins. 4 April 2022. Available online: https://www.gfrlaw.com/what-we-do/insights/climate-solutions-now-act-2022 (accessed on 27 October 2022).
29. Harford, T. Climate Change and the Prisoner's Dilemma, Financial Times. 24 January 2020. Available online: https://www.ft.com/content/5312691c-3d3c-11ea-b232-000f4477fbca (accessed on 27 October 2022).
30. Bearak, M. Climate Pledges Are Falling Short, and a Chaotic Future Looks More Like Reality, New York Times. 26 October 2022. Available online: https://www.nytimes.com/2022/10/26/climate/un-climate-pledges-warming.html (accessed on 27 October 2022).
31. Da Silva, C. World 'Nowhere Near' Hitting Climate Targets, U.N. Warns, NBC News. 26 October 2022. Available online: https://www.nbcnews.com/news/world/world-emissions-paris-climate-targets-un-report-rcna54044 (accessed on 27 October 2022).
32. Weston, P.; Greenfield, P. The World Made a Biodiversity Pact, and of Course We Aren't Part of It. *Mother Jones* 2022. Available online: https://www.motherjones.com/politics/2022/12/cop15-2022-un-biodiversity-convention-united-states/ (accessed on 12 December 2022).
33. The White House. Executive Order on Tackling the Climate Crisis at Home and Abroad. 27 January 2021. Available online: https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/ (accessed on 12 December 2022).
34. U.S. Department of the Interior. Fact Sheet: President Biden to Take Action to Uphold Commitment to Restore Balance on Public Lands and Waters, Invest in Clean Energy Future. 2021. Available online: https://www.doi.gov/pressreleases/fact-sheet-president-biden-take-action-uphold-commitment-restore-balance-public-lands (accessed on 12 December 2022).