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Countries' commitments to soil organic carbon in Nationally Determined Contributions

Liesl Wiese [a], Eva Wollenberg[b], Viridiana Alcántara-Shivapatham[c], Meryl Richards[d], Sadie Shelton[b], Susanna Esther Hönle [e], Claudia Heidecke[e], Beáta Emoke Madari[f] and Claire Chenu[g]

[a]International Agricultural Science and Policy Consultant, South Africa; [b]CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) and Gund Institute for Environment, University of Vermont; [c]Federal Office for Agriculture and Food, Germany (BLE); [d]Ceres; [e]Thünen Institute; [f]Brazilian Agricultural Research Corporation (Embrapa); [g]AgroParisTech

ABSTRACT

Soil carbon is the major active pool of terrestrial carbon, and as such, soil organic carbon (SOC) targets, policies and measures will be pivotal to achieving global climate targets. SOC sequestration may reduce the net annual greenhouse gas emissions from Agriculture, Forestry and Other Land Use by between 3% and 71%, while simultaneously supporting various ecosystem services. Accurate SOC accounting and monitoring, however, is constrained by various technical challenges related to indicators, rates of SOC change, measuring the impact of management practices on SOC, and the long-term persistence of sequestered SOC. We assessed countries' pledges to the Paris Agreement for SOC in agriculture to better understand the level, transparency, and specificity of commitments. Reviewing 184 countries' initial Nationally Determined Contributions (NDCs), we considered whether SOC was included, what was pledged, the level of ambition promised and the specificity of mitigation targets. Twenty-eight countries referred to SOC in their NDCs, citing quantified or unquantified mitigation targets, national policies or programs, and actions and measures to be implemented in agricultural lands (14), peatlands (6) or wetlands (14). Countries' reasons for not including SOC in NDCs included the need to prioritize goals of sustainable development and food security above climate mitigation, a lack of incentives for farmers to improve management practices, and the difficulty of accurately monitoring changes in SOC. Including SOC targets in NDCs can improve NDCs' comprehensiveness and transparency to track and compare policy progress across NDCs; it can also leverage SOC-related climate finance, technical support, and capacity building.

Key policy insights

1. Many NDCs specify practices known to have the potential to achieve SOC sequestration or protection without explicitly mentioning SOC. The SOC-related mitigation potential of these practices can be quantified in future NDCs.
2. NDCs are not presently a good indicator of countries' interest or commitment to SOC action at national level. To improve this, countries with existing SOC policies, programs, and actions can specify their SOC-related commitments in future NDCs.
3. Increased collaboration between countries with experience managing SOC and countries needing support to develop SOC-related targets, policies, measures and incentives for land users and farmers would facilitate the provision of such needed support.

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CONTACT Liesl Wiese liesl.wiese76@gmail.com International Agricultural Science and Policy Consultant, South Africa

4. To increase country commitments and attention to managing SOC, there is a need for improved SOC measurement and monitoring, for better evidence on the impacts of management practices on SOC, and for incentives for farmers to change practices and overcome barriers.

Introduction

Recent attention and raised expectations about soil organic carbon's (SOC) potential to contribute to climate change mitigation and adaptation, is reflected by a number of global initiatives such as the 4 per 1000 Initiative (Soussana et al., 2019), Global Soil Partnership (FAO, 2019), Nature-Based Solutions (Griscom et al., 2017), Sustainable Development Goal 15.3 (Orr et al., 2017) and the Koronivia Joint Work on Agriculture (UNFCCC, 2018a). SOC sequestration and protection can contribute to negative emissions and avoided emissions to help achieve 2050 and 2100 global policy targets (IPCC, 2014). The annual carbon sequestration potential in global mineral soils is estimated at 0.4-8.6 Gt CO_2eq with high confidence in relation to management practices (Jia et al., 2019). This may reduce net annual GHG emissions from the Agriculture, Forestry and Other Land Use (AFOLU) sector (~ 10–12 GtCO_2eq/yr) (IPCC, 2014) from 3% up to 71%. Furthermore, an estimated 600 Gt of carbon is stored in carbon-rich peatlands, which may be lost if they are not protected and instead exploited for agricultural production (Leifeld and Menichetti, 2018; Rumpel et al., 2020). In addition, SOC sequestration can support various ecosystem services related to climate change adaptation, food security and biodiversity (Sykes et al., 2020) due to increased soil fertility, improved moisture retention, improved water availability to plants (Halldorsson et al., 2015; Paustian et al., 2019; Smith, 2016), reduced soil erosion and improved habitat for various forms of biodiversity (Griscom et al., 2017).

Yet, debate about what is possible to achieve and how to monitor or verify improvement in SOC has challenged progress on the ground (Rumpel et al., 2020; Zomer et al., 2017). While monitoring standards exist (FAO, 2020), accurate monitoring of SOC stock changes has been constrained by the lack of simple and robust indicators, slow rates of SOC change, (Bruun et al., 2013; Paustian et al., 2019), insufficient precision of SOC stock assessment (Goidts et al., 2009), and the difficulty of determining the long-term persistence of sequestered SOC (Cotrufo et al., 2019). Soils' capacity to store carbon may be vastly overestimated due to models that overpredict carbon stabilization (He et al., 2016), incorrect assumptions about soil conditions (Smith et al., 2005) and a lack of accounting for the finite and reversible nature of SOC sequestration (Powlson et al., 2011). Biophysical limits constrain potentials, such as availability of continuous organic matter inputs or critical nutrients such as nitrogen and phosphorous (Rumpel et al., 2020). Some measures expected to increase soil carbon sequestration, such as use of fertilizer or irrigation, lead to additional greenhouse gas (GHG) emissions in their lifecycle (Schlesinger and Amundson, 2019). Policy and economic incentives are also weak in most countries (Amundson and Biardeau, 2019).

The 2015 Paris Agreement of the United Nations Framework Convention on Climate Change (UNFCCC) established Nationally Determined Contributions (NDCs) as a mechanism for countries to set ambitious, voluntary mitigation commitments and priority actions for adaptation (United Nations, 2015). Increased attention and debate around SOC are driving ideas for solutions and increasing pressure for national governments to consider SOC as part of their climate mitigation and adaptation strategies (Paustian et al., 2019; Vermeulen et al., 2019). Building on an existing international agenda for restoring soil health, SOC advocates have sought better inclusion of SOC sequestration and related management practices in the NDCs (Beasley et al., 2019; Breakthrough Strategies and Solutions, 2017).

Because SOC is the major terrestrial carbon pool (Ciais et al., 2013), specification of SOC targets, policies and measures is pivotal to achieving global targets and therefore necessary to include in the NDCs (Griscom et al., 2017; Paustian et al., 2019; Vermeulen et al., 2019). Including information about SOC in the NDCs, as part of the national inventory sources and sinks of emissions, can provide a transparent basis for tracking intended mitigation and for guiding national action, including coordination of funding and technical assistance provided to countries.

Given the important potential role of SOC in climate change mitigation and adaptation, particularly for agriculture, the purpose of this paper is to assess countries' NDCs for their inclusion of SOC sequestration or avoided SOC loss in agricultural soils. We examined the first cycle of NDCs to determine: 1) whether SOC is addressed; 2) how SOC is included and the level of specificity in relation to mitigation targets; and 3) why countries included SOC or not in their NDCs. We also review technical SOC sequestration and protection potentials to compare these to countries' commitments. We draw conclusions about how to move forward on SOC-related agricultural mitigation targets and on related adaptation priorities in future NDCs. Additional details on the study methods, results and discussion points are provided in the supplementary materials.

SOC potentials

Many countries have significant technical potential for sequestering and protecting SOC based on environmental conditions, soil properties (Wiesmeier et al., 2019), land use practices (Zomer et al., 2017), or historical carbon loss (Sanderman et al., 2018). SOC sequestration is defined here as the long-term (> 20 years) increase and storage of carbon stocks in soil as stable forms of organic matter – an adaptation of the definition by Chenu et al. (2019). Countries with large agricultural areas, in agroecological zones favorable to SOC formation and accumulation, or with high historical SOC losses have a high potential to sequester SOC. Similarly, countries with large areas of wetlands, peatlands and other carbon-dense soils have significant potential to protect SOC and prevent GHG emissions.

SOC can occur in both stable and labile forms of soil organic matter (SOM). The long-term storage of SOC in stable forms of SOM is important for the mitigation of climate change. Conversely, SOC in labile SOM is essential to support soil fertility, soil physical properties and soil biodiversity (Chenu et al., 2019). Stable forms of carbon can occur due to protection from decomposition by microorganisms through association with soil minerals, or protection within inaccessible pores (Lützow et al., 2006). Labile forms occur where microorganisms can access the easily decomposable organic matter (Six et al., 2002).

Numerous land use and management practices are known to improve SOC sequestration or protection, which include avoided conversion or drainage of peatlands (Crump, 2017), grassland and crop residue management, use of cover crops and green manure, applying organic amendments (such as manure, compost, biochar), integrated soil fertility management, avoided open burning, use of nitrogen fertilizer, conservation agriculture, reduced or no-tillage, fallow, agroforestry, silvo-pastoralism, and use of deep-rooted species (Boddey et al., 2010; Cardinael et al., 2018; Chotte et al., 2019; Conant et al., 2017; Corbeels et al., 2016; Minasny et al., 2017; Paustian et al., 2016; Zomer et al., 2017). Impacts on SOC sequestration may vary depending on climate, soil type and land use history (among other factors), and study methods often vary in terms of depth of soil studied and the calculation method used to determine SOC change, making results difficult to compare (Chenu et al., 2019; Meurer et al., 2018; Olson et al., 2014; Powlson et al., 2016).

Some practices involve trade-offs with other GHG emissions (Lugato et al., 2018; Paustian et al., 2019) such as CH_4 and N_2O, which have 100-year global warming potentials of 28 and 265 times that of CO_2 respectively (Jia et al., 2019). The use of nitrogen fertilizer can increase SOC by enhancing plant productivity and therefore increasing organic matter inputs to the soil, however nitrogen fertilizer use also produces N_2O emissions (Lugato et al., 2018). The application of organic amendments to increase SOM on the other hand, can release less N_2O emissions, but contribute more CH_4 (Rahman et al., 2019). Similarly, the energy used for biochar production may release more CO_2 than the carbon biochar can sequester. Caution is needed to ensure that biochar does not increase organic inputs in one location at the cost of decreasing it in another by transferring plant biomass (Whitman et al., 2010). Evaluation of trade-offs and site-specific impacts across different practices is therefore necessary to accurately determine SOC sequestration potential and the net climate impacts of specific practices.

Methods

Scope of agricultural practices covered in the NDCs

In this paper, 'agriculture' in the NDCs refers to, first, any mention of agricultural land or soil, as well as cropland, grassland, peatland or wetland, and second, contributing to economy-wide targets (agriculture implicitly included), specified agriculture sector targets, or related components in the AFOLU or Land Use, Land Use Change and Forestry (LULUCF) sectors.

We do not distinguish between UNFCCC Common Reporting Format categories under the UNFCCC (UNFCCC, 2013) and the IPCC guidelines for national GHG inventories (IPCC, 2006) for Agriculture and LULUCF. As highlighted by Hönle et al. (2019), the emission source category under agriculture considers only CH_4 and N_2O emissions while CO_2 fluxes related to agricultural land use and land use change are accounted for under the LULUCF category.

We analyzed the agricultural adaptation and mitigation contributions of 184 NDCs submitted to the UNFCCC up to 24 November 2019. NDCs were examined for: 1) explicit mention of SOC in mineral or organic (peatland or wetland) soils in relation to agriculture; and 2) mention of other practices or measures that may sequester or protect SOC.

Explicit mention of SOC, peatlands and wetlands

To analyze explicit mention of SOC in relation to mineral or organic soils, we reviewed prior analyses of agriculture in the NDCs by Richards et al. (2016) and Hönle et al. (2019). To broaden the potential inclusion of SOC in organic soils, explicit mention of peatlands and wetlands in the NDCs were analyzed, based on the measures and keywords in Table 1.

Since guidance under the Paris Agreement for the preparation of NDCs is non-binding, NDCs are heterogeneous in length, coverage and level of detail (FAO, 2016). Consequently, to systematize our assessment, we paid attention to information provided in NDCs about: 1) commitments to mitigation targets (unconditional or conditional); 2) actions or measures to be implemented; 3) national policies/plans/assessments/programs to support national climate change actions or targets; and 4) other contexts.

Mention of practices or measures affecting SOC

We identified NDC commitments related to agricultural measures that would protect or sequester SOC in organic or mineral soils, such as the use of organic amendments (manure, compost, biochar), grassland and pasture management, agroforestry and silvo-pastoralism, reduced or no-tillage, and erosion control. For this part of the assessment, we relied on the keyword analysis done by Richards et al. (2016). In addition, we analyzed revised or first NDCs submitted to the UNFCCC after 31 October 2016 until 24 November 2019 for the measures and keywords listed in Table 1 using the methodology of Richards et al. (2016).

Table 1. Measures and keywords used to identify NDC commitments that would affect SOC.

NDC analysis	Measures	Keywords
SOC	Soil carbon sequestration or protection	Soil carbon, soil C, soil organic carbon
Peatland and wetland	Protection or restoration of peatlands and wetlands	Peatland, wetland, high-carbon, high carbon
Measures or practices that would protect or enhance SOC	Agroforestry/silvo-pastoralism	Agroforestry, agro-forestry, silvopastoral, silvo-pastoral
	Conservation agriculture	Climate-smart agriculture, climate smart agriculture, CSA, conservation agriculture
	Reduced or no-tillage	Tillage, tilling
	Residue retention (mulching)	Residue, mulch, agricultural waste
	Cover crops	Cover crop, crop patterns
	Organic amendments (manure, compost, biochar)	Fertilize, fertilizer, manure, compost, biochar, organic
	Grassland/pastureland management	Grassland, pasture, rangeland, grazing
	Integrated soil fertility management	Soil, soil fertility, ISFM
	Fallow	Fallow, agricultural waste
	Erosion control	Erosion, soil erosion
	Reduced/stopped (crop residue) burning	Burn, fire, residue

Note: The analysis of NDC reference to SOC, peatlands and wetlands was based in part on the prior analyses of agriculture in NDCs by Richards et al. (2016) and Hönle et al. (2019).

Results were analyzed to determine the number of countries specifying the relevant groups of measures under mitigation or adaptation.

Identifying countries with high technical potentials for SOC sequestration and protection

We identified countries with high potential to sequester SOC in croplands (Zomer et al., 2017), with high potential to protect existing SOC stocks based on areas of high-carbon (organic) soils (Zomer et al., 2017), with high total SOC stocks at 0-30 cm of soil depth (FAO and ITPS, 2018), and with large areas of peat and their estimated carbon stocks (Crump, 2017). The data from Zomer et al. (2017) broadly categorizes countries with high SOC sequestration potentials in croplands, rather than potentials in agricultural lands.

Ten countries stored more than 60% of the total global SOC stock at 0-30 cm, with the top five countries holding more than 50% of the stock; from highest to lowest SOC stocks, these are: Russia, Canada, USA, China, Brazil (FAO and ITPS, 2018). These five countries were also amongst the top 10 countries with the

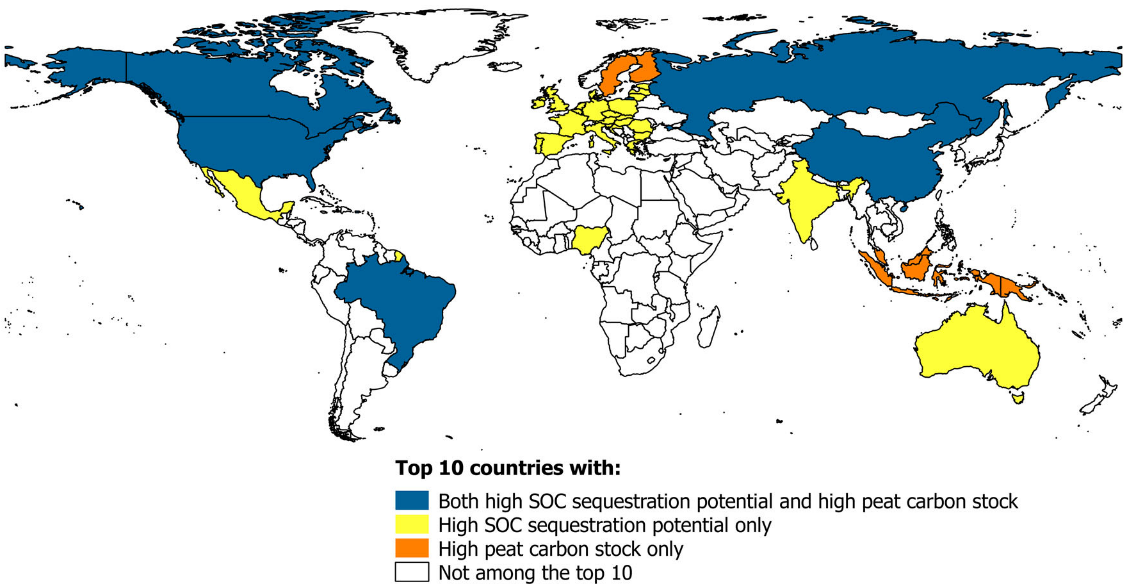

Figure 1. Top 10 countries with highest potential to sequester SOC in croplands (20-year period, medium sequestration rate scenario) and to retain largest peat carbon stocks. Source: Zomer et al. (2017) for sequestration potential and Crump (2017) for peat carbon stocks.

Table 2. Top 10 UNFCCC parties with the potential to sequester the highest annual increment of SOC in croplands over 20 years and the largest peat carbon stocks.

Rank	Country	SOC sequestration potential (Mt C yr^{-1}) (Zomer et al., 2017)	Country	Peat C stock (Mt C) (Crump, 2017)
1	**USA**[a]	124.7	**Canada**	139,819
2	India	103.8	**Russia**	124,762
3	EU[b]	84.5	Indonesia	48,993
4	**China**	65.4	**USA**	26,454
5	**Russia**	62.6	Papua New Guinea	5,427
6	Australia	36.2	**Brazil**	4,934
7	**Brazil**	35.9	Malaysia	4,926
8	**Canada**	26.8	Finland	4,802
9	Mexico	21.1	Sweden	4,535
10	Nigeria	19.8	**China**	2,924

Source: Zomer et al. (2017) for sequestration potential and Crump (2017) for peat carbon stocks
[a]Countries in **bold** appear in both categories.
[b]The 28 European Union (EU) countries have a single NDC; a cumulative SOC sequestration potential of 84.5 Mt C yr^{-1} based on data from Zomer et al. (2017) for 27 of these countries (data for Malta not available) puts the EU in third position globally, between India and China.

potential to sequester the highest total amounts of SOC in croplands over 20 years (Zomer et al., 2017) and the top 10 countries with the largest peat carbon stocks to be protected (Crump, 2017) (Figure 1, Table 2).

Since the 28 European Union (EU) countries have a single NDC and Zomer et al. (2017) provides data per country, the aggregate SOC sequestration potential for the EU was calculated as 84.5 Mt C yr^{-1}. This puts the EU in third position, between India and China (see Table 2), even though data were not available for Malta which means the EU value is the sum for only 27 countries. The same summation of peat carbon stocks in the EU was not possible since Crump (2017) presented data for the top 20 countries only. As a result, the high SOC sequestration potential in the EU is not reflected in Figure 1. Furthermore, Crump (2017) noted that their data on peat carbon stocks presented for the top 20 countries excluded recent discoveries in the Congo Basin and Peru which may affect the global rankings.

Interviews with national experts

Interviews were conducted with eight soil carbon experts and NDC development experts from eight countries, representing national or subnational government, to understand the rationale underlying agricultural NDC commitments and potential constraints to including SOC targets in NDCs. Countries were selected based on: 1) high technical potentials for SOC sequestration and protection; and 2) whether SOC is explicitly mentioned under agriculture in their NDC, based on the keyword search. The resulting eight countries covered by interviews were Brazil, Burkina Faso, Canada, China, EU, Indonesia, Japan, and USA. One key respondent was identified in each country based on their overall understanding of the NDC process and national processes related to SOC. Interview results were treated as anonymous inputs and do not represent official statements from countries.

Interview responses were used as background information to contextualize how different countries viewed the importance of SOC sequestration and protection and its role in the NDCs, challenges associated with including SOC in NDCs, and considerations for future inclusion of SOC-related targets or actions in NDCs.

Results: SOC, peatlands, wetlands and measures or practices affecting SOC under agricultural NDC commitments

A total of 28 NDCs referred to SOC in agriculture (14), peatlands (6) or wetlands (14), with some NDCs referring to more than one of these aspects (Table 3). Additional information on NDC context and text related to SOC, peatlands and wetlands is provided in supplementary material, Annex 1 (see Supplementary Material).

Soil organic carbon (SOC)

Of the 14 NDCs referring to SOC, 13 linked SOC explicitly to mitigation targets and one (Syria) mentioned (soil) organic matter under adaptation without links to mitigation targets. Seven countries provided quantified information related to SOC as an outcome of measures to be implemented under an economy-wide target, multi-sectoral target, sectoral target, or sub-sectoral target. Five countries referred to SOC as part of their mitigation target but did not quantify the contribution. Only one country described SOC as a quantified co-benefit of adaptation projects. Countries' commitments to explicit SOC mitigation targets can be categorized as follows:

1. SOC protection or sequestration as an unquantified outcome contributing to:
    a. An unconditional mitigation target (Armenia, China, Zambia).
    b. A conditional mitigation target (Pakistan, Palestine).
2. SOC protection or sequestration as a quantified outcome contributing to:
    a. An unconditional mitigation target (Bolivia, Canada, Japan, Namibia, Nepal).
    b. An unconditional mitigation target and a more ambitious conditional mitigation target (Malawi, Uruguay).
3. SOC protection or sequestration as a quantified mitigation co-benefit resulting from the implementation of adaptation projects (Burkina Faso).

Table 3. How countries referred to agricultural SOC, peatlands or wetlands (✓) in their NDC.

	SOC		Peatlands		Wetlands	
Country	Specified?	What was mentioned?	Specified?	What was mentioned?	Specified?	What was mentioned?
Afghanistan			✓	CT, A		
Armenia	✓	UT, A				
Bangladesh					✓	A
Belarus			✓	UT, A		
Belize					✓	*P*, A
Bolivia	✓	UT, A			✓	A
Burkina Faso	✓	UT, A				
Burundi			✓	*P*		
Canada	✓	UT, *P*, A			✓	UT, *P*, A
China	✓	UT, A			✓	UT, A
Iceland					✓	UT, A
Indonesia			✓	UT, CT, *P*, A	✓	UT, A
Japan	✓	UT, A				
Malawi	✓	UT, CT, A				
Malaysia			✓	O		
Namibia	✓	UT, A				
Nepal	✓	UT, *P*, A				
Nicaragua					✓	*P*
Pakistan	✓	CT, *P*, A			✓	*P*
Palestine	✓	CT, A				
South Sudan					✓	A
Suriname					✓	UT, CT, *P*
Syria	✓	A				
Uganda					✓	UT, *P*, A, O
UAE[a]					✓	UT, A
Uruguay	✓	UT, CT, *P*, A	✓	UT, CT, *P*, A	✓	UT, CT, A
Vietnam					✓	UT
Zambia	✓	UT, A				

[a]UAE = United Arab Emirates

Key: unconditional (UT) or conditional (CT) mitigation targets; national policies/plans/assessments/programs (*P*) related to climate change; actions or measures to be implemented (A); or other contexts (O).

The eight NDCs providing quantified information related to SOC applied various quantitative indicators as follows:

1. Net GHG emissions and removals (Canada, Japan, Namibia)
2. Quantitative indicators for a specific measure(s) (Malawi)
3. Percentage or hectares of land area where SOC will be preserved or sequestered (Bolivia, Nepal, Uruguay)
4. Quantitative mitigation co-benefits of adaptation actions (Burkina Faso).

Of these eight NDCs, only those for Burkina Faso, Namibia, and Uruguay provided quantified indicators for SOC specifically. In the other five NDCs, SOC is a component in a broader quantified target or indicator to be achieved from the implementation of measures which may fall under the same sector (Japan, Malawi, Nepal) or multiple sectors (Bolivia, Canada).

Some NDCs indicated practices linked to SOC sequestration or protection, such as agroforestry (Malawi, Palestine), conservation agriculture (Zambia), no-till farming (Uruguay), residue retention (Malawi, Uruguay), cover crops (Uruguay), applying organic amendments such as manure and crop residues (Malawi), restoring or regenerating grassland vegetation (China, Japan, Uruguay), and conserving (Uruguay) or restoring (China) peatlands and wetlands.

Three NDCs (Canada, Pakistan, Uruguay) specified national policies, plans or assessments that support national climate change targets or actions, along with descriptive text indicating that these documents address SOC.

Peatlands and wetlands

Only six NDCs mentioned peatlands. In all but one instance, peatlands were linked to unconditional or conditional mitigation targets, mainly as unquantified (Afghanistan, Burundi) or quantified (Belarus, Indonesia, Uruguay) outcomes from the implementation of other measures. In most cases, peatlands' contribution to mitigation targets was specified or for this analysis was interpreted to be related to SOC or carbon, except for Afghanistan which specified the reduced use of peat soils in contribution to a reduction in N_2O emissions. In three NDCs, peatlands were clearly linked to policies or plans (Uruguay), assessments (Indonesia) or programs (Burundi) related to mitigation.

Wetlands were specified in numerous contexts within the NDCs, which can be categorized as:

1. Wetland protection, restoration, or increased carbon storage in wetlands as quantified (Canada, Uganda, Uruguay) or unquantified (China, Iceland, Indonesia, Suriname, Vietnam) outcomes in contribution to mitigation targets.
2. Policies, plans, and potentials related to wetland protection, management, or enhanced wetland carbon sinks under adaptation (Belize) or mitigation (Canada, Nicaragua, Pakistan, Uganda).
3. Adaptation actions with unspecified mitigation co-benefits through the implementation of strategies and plans that aim to improve the understanding of wetlands, as well as actions to restore mangroves (United Arab Emirates).
4. Adaptation measures related to wetland conservation or restoration (Bangladesh, Bolivia), including in an intended NDC only (South Sudan has not submitted a NDC at the time of analysis).

Mention of other practices or measures affecting SOC

Numerous NDCs mentioned the implementation of practices that would support the sequestration or protection of SOC under agricultural mitigation or adaptation sections. The full data collected are provided in Annex 2. Table 4 summarizes NDCs with SOC-relevant practices, even if SOC was not mentioned. The most common practices listed under mitigation were agroforestry and silvo-pastoralism (31 countries), conservation agriculture (21), grassland and pastureland management (14), organic amendments (12) and reduced/stopped crop residue burning (12). Under adaptation, the most common practices were erosion control (41 countries), agroforestry and silvo-pastoralism (36), grassland/pastureland management (16), conservation agriculture (13) and integrated soil fertility management (13).

Discussion

Our analysis shows that, despite the important role of SOC in climate change mitigation and adaptation (Sykes et al., 2020), most countries' NDCs do not directly reflect this potential or its relevance for reducing further emissions. Based on our analysis of 184 NDCs, only 28 countries referred to SOC, peatlands or wetlands, with just 14

Table 4. Number of countries listing the implementation of other SOC-relevant measures.

Measure/s	Mitigation	Adaptation
Agroforestry/silvo-pastoralism	31	36
Conservation agriculture	21	13
Grassland/pastureland management	14	16
Organic amendments (manure, compost, biochar)	12	10
Reduced/stopped (crop residue) burning	12	6
Erosion control	9	41
Integrated soil fertility management	6	13
Reduced or no-tillage	5	6
Residue retention (mulching)	3	3
Cover crops	2	1
Fallow	1	1

Note: These are measures that would support the sequestration or protection of SOC under agricultural mitigation or adaptation. Measures listed here exclude peatland and wetland protection or restoration that are captured in Table 3.

of these referring to SOC. SOC was mainly addressed in relation to mitigation targets, as an outcome of actions or measures to be implemented, and in the context of national policies, plans, assessments or programs related to climate change. These results are discussed in the context of requirements for NDC target setting under the Paris Agreement, priorities and challenges faced by countries in setting SOC-related NDC targets, and options for countries electing to specify SOC in future NDCs.

Paris Agreement requirements

While few countries specified SOC targets, policies, or actions, evolving guidance on NDCs indicates that more comprehensive specification is encouraged. Under the Paris Agreement, parties are to 'strive to include all categories of anthropogenic emissions or removals in their Nationally Determined Contributions' (UNFCCC, 2019, p. 7) and provide the 'information necessary [in their NDCs] for clarity, transparency and understanding' (ICTU) (UNFCCC, 2019, p. 6). Developed countries are required to commit to 'economy-wide absolute emission reduction targets,' while developing countries should only 'move over time towards economy-wide emission reduction' (Article 4.4) (United Nations, 2015, p. 4). In addition, support shall be provided to developing countries 'to enhance the capacity of developing country Parties in preparing, communicating and accounting for their Nationally Determined Contributions' (UNFCCC, 2019, p. 6).

The Paris Agreement Work Program (2018) provides details on features of NDCs, ICTU and accounting for Parties' NDCs (Ad Hoc Working Group on the Paris Agreement, 2018). The draft rulebook for implementing the Paris Agreement, known as the Katowice Climate Package (UNFCCC, 2018b), provides further details, including modalities, procedures and guidelines for transparency (UNFCCC, 2019). According to the Katowice Climate Package, parties should set mitigation targets that 'strive to include all categories of anthropogenic emissions or removals in their Nationally Determined Contributions' (UNFCCC, 2019, p. 7). For purposes of clarity, transparency and understanding, parties should also indicate their 'sector-, category- or activity-specific assumptions, methodologies and approaches' (UNFCCC, 2019, p. 10).

Specifying SOC targets, policies or actions can therefore provide more comprehensive and transparent information about countries' ambition to pursue the 1.5°C or 2°C policy target of the Paris Agreement. Specification would also provide more detail for tracking progress and flexibility for accounting that is appropriate to the subsector and may demonstrate enhanced ambition. This may be especially relevant to countries with high technical potential for SOC sequestration in croplands or SOC protection in peatlands (Table 2). Of the top ten countries presented in Table 2, only Canada, China and Indonesia specified SOC, peatlands or wetlands in their NDC in relation to mitigation targets.

Furthermore, developing countries' needs related to financial, technology and capacity building support could be indicated in the specification of SOC targets, policies, or actions. This would signal where concerted support and efforts are needed to improve countries' ability to harness the potential of SOC protection and sequestration as both GHG mitigation and adaptation strategies.

Country priorities, challenges, and suggested solutions

From the interviews with experts it was evident that extensive policies, programs, actions or targets related to SOC exist in the USA, Brazil, and EU, which are also amongst the top 10 countries or regions with high technical potential to sequester SOC in croplands (Table 2). These domestic actions and policies were not consistently reflected in NDCs or linked to SOC. For example, the USA's 'USDA Building Blocks for Climate Smart Agriculture and Forestry' (USDA, 2016) plan provides a range of technologies and practices to increase carbon storage in biomass and soil and the estimated mitigation contributions of such practices. Yet the USA's NDC makes no specification of SOC-related sectors, measures, or actions. The NDC instead has an economy-wide mitigation target and states that 'a number of existing laws, regulations and other domestically mandatory measures are relevant to the implementation of the target.' In the EU, an economy-wide NDC target was set and the EU does not foresee targeting single sectors separately in future. Yet SOC is currently regulated in the EU through the Land Use, Land Use Change and Forestry Regulation. The Post 2020 Common Agricultural Policy reform package and the 'Farm to Fork Strategy' foresee enhanced conditionality for good soil management. SOC was not specified in NDCs of USA, Brazil and EU, despite these parties having significant domestic soil carbon-related policies. NDCs, therefore, do not necessarily reflect domestic action, policies and targets concerning SOC.

Based on the expert interviews, countries chose not to specify SOC in their NDC for several reasons. First, countries have different perspectives and approaches to: whether SOC sequestration and protection are a priority for NDC commitments within the bigger context of agriculture, food production and climate change; and how agriculture should be addressed in the NDCs vis-à-vis economy-wide commitments. Experts from Burkina Faso and Brazil, for example, explained that because the central role of agriculture is food production for food security, SOC sequestration is an important function of soil, but not a goal of agriculture. Adaptation for regenerating agricultural soils is the priority to support food security in Burkina Faso, where the economy is dominated by the agricultural sector, hence mitigation is reported only as a co-benefit of adaptation. This argument reflects the political stance of many developing countries that the agriculture sector should not be targeted for mitigation due to their need for low-cost food production and international food justice. Furthermore, experts from Brazil highlighted that NDCs are national level commitments to sustainable development and climate change that need to be addressed through transversal, economy-wide commitments which, by definition, include all GHG emission sectors.

Second, countries face numerous challenges to quantifying and monitoring SOC, including countries that specified SOC in their NDCs. These challenges include the accuracy, affordability, and availability of data for measurement, reporting, verification (MRV) and monitoring of changes in SOC (Brazil, China, Indonesia, USA) or inferring such SOC changes based on the implementation of management practices (Canada, Indonesia, USA). Poor data hampers not only SOC target setting and monitoring, but also the identification and tracking of relevant measures or practices that may be included in NDCs. In contrast, Japan, which has a detailed SOC mitigation target, has a national program for the long-term monitoring of agricultural soil, which monitors fixed points for physiochemical soil properties and records soil management information through questionnaires. The soil chemical data includes SOC, while SOC stock changes in croplands and CH_4 emissions from rice cultivation are modelled using a modified RothC[1] model and DNDC-Rice[2] model, respectively. This data collection and modelling enabled Japan to develop an agricultural mitigation target based on sound science applying an IPCC Tier 3 approach to the Japanese National GHG Inventory Report from 2015.

Experts also indicated the importance of a clear scientific understanding of the impacts of different land management practices on the carbon balance (Brazil, Canada) and the ability to effectively monitor implementation and changes in those practices (Brazil, Canada, Indonesia) in the national GHG inventories as potential constraints. Experts stated the need for research on soil and soil restoration for agriculture and food production (Brazil, Burkina Faso), and the need to quantify the impact of specific measures on SOC sequestration. Improving SOC inventories requires enhanced national capacity to gather relevant activity data in these areas and to develop country-specific emission factors and SOC targets.

Finally, beyond monitoring challenges, several countries highlighted the need for information on economic benefits for land users or farmers to support the implementation of measures or practices related to SOC, as a factor affecting SOC's inclusion in NDCs (Canada, EU, Indonesia, Japan, USA). In one country (Indonesia) it was emphasized that farmers are more likely to adopt practices or products with more attractive economic benefits or where rewards are provided based on achieved results. Incentives, however, do not guarantee implementation. In Japan, subsidies were given to farmers to use compost, but the labor intensiveness of composting created a disincentive. Ultimately, experts suggested that farmers will require a combination of financial, technological, and other support mechanisms to shift to practices that sequester more SOC.

Despite the challenges faced in setting SOC related mitigation targets, interviewed experts recommended seven types of solutions to improve SOC commitments in future NDCs, along with associated targets, as follows:

1. Developing monitoring systems that are practical and cost-effective to better quantify and monitor changes in SOC resulting from the implementation of selected measures or practices. These systems could include:
    a. Indicators for the assessment and reporting of progress toward SOC protection and sequestration.
    b. Improving national and sub-national statistical systems for relevant indicators.

2. Ensuring that the national GHG inventory has the capacity to incorporate, separate and track SOC activity data and indicators.
3. Identifying measures and practices that:
   a. Are scientifically proven to protect, store or sequester SOC (permanently) within the national context.
   b. Provide measurable economic benefits that are more attractive to farmers/land users
   c. Can be tracked for national GHG inventories
   d. Can be upscaled and transferred to more regions
4. Considering sectors and practices that can be controlled, regulated, or legislated to ensure the long-term implementation of measures to reach specified targets.
5. Avoiding return to practices detrimental for SOC.
6. Supporting farmers through financial, technological, capacity, and other incentives or mechanisms.
7. Identifying the barriers preventing implementation of practices to adjust targets accordingly and find appropriate solutions to overcome such barriers.

Options to specify SOC in future NDCs

Based on this analysis of the NDCs and country examples, specifying SOC in the NDCs show a range of means for increasing NDC ambition and transparency by incorporating SOC mitigation and adaptation measures and practices. Options to improve ambition and transparency in future NDCs include:

1. Increasing NDC mitigation ambition by:
   a. Quantifying the mitigation impact of existing or future national actions for SOC protection or sequestration.
   b. Quantifying the mitigation co-benefits of existing or future adaptation actions that would protect or sequester SOC over the long-term (e.g. Burkina Faso).
2. Increasing transparency for global SOC accounting by:
   a. Specifying and including SOC in multi-sectoral sub-targets (e.g. Canada).
   b. Improving national and sub-national statistical systems for relevant indicators and within national GHG inventories.
   c. Specifying and including SOC in sectoral sub-targets (e.g. Japan, Uruguay, Namibia).
3. Leveraging support for relevant national policies, technical capacity development and climate finance by:
   a. Specifying SOC in relation to measures already included in NDCs under agricultural mitigation or adaptation that would support the sequestration or protection of SOC (Table 4).
   b. Setting conditional mitigation targets for developing countries that may depend on financial, technical, or capacity development support (e.g. Palestine, Uruguay).

Conclusions

Despite widespread political and scientific interest in soil carbon as a strategy for climate change mitigation and adaptation in agriculture, SOC was explicitly addressed by only 15% (28) of the 184 analyzed NDCs, with varying levels of detail and links to mitigation targets. These NDCs addressed both the adaptation and mitigation impacts of SOC, as well as the protection of existing SOC and enhancing SOC in existing agricultural land. The countries with the highest potential for soil carbon protection or sequestration generally did not specify SOC in their NDCs.

However, the lack of attention to SOC in the NDCs by most countries does not necessarily reflect a lack of interest or action by national governments. We found evidence of countries with strong domestic SOC policies, but no specification of SOC in their NDC (e.g. in Brazil, EU and USA). Other countries said they were sincerely interested in including soil carbon in NDCs, but lacked technical capacities. Thus, NDCs should not be used as an indicator of countries' lack of interest or commitment to SOC action. Rather, countries rationally opted not to include SOC in this first round of NDCs for a range of reasons, often more specific to the context and requirements of the NDCs themselves.

At least three reasons explained countries' actions, according to our interviews. First, some countries provided economy-wide GHG emission reduction commitments without specifying commitments under agriculture or subsectors of agriculture. This raises the question to what extent should countries specify targets and actions for SOC at sector and subsector levels, to improve transparency and to provide sufficient information for clarity, understanding and tracking purposes.

Second, some countries viewed SOC protection or sequestration as a co-benefit not warranting detail in the NDC, rather than as a targeted policy goal. This raises related transparency and information issues about the value of accounting for co-benefits and how to best do this.

Third, some countries did not include SOC due to accounting difficulties. Notable accounting challenges include: a lack of accurate, affordable data or suitable SOC MRV; the difficulties of monitoring changes in SOC over time and linking management practices to changes in SOC; identifying and tracking relevant measures at national level; ensuring that national GHG inventories can accommodate selected data and indicators; and assuring the permanence of the desired effect of implemented measures. Accounting difficulties suggest that more countries would include SOC in their NDCs if these technical issues could be overcome.

While these results may not capture all countries' rationales for including or not including SOC in the NDCs, they do suggest that countries' motivations and capacities for SOC accounting affect accounting for SOC in the NDCs. The results also point to questions about the level of specificity of sectors, subsectors and co-benefits required in NDCs in general (not only for SOC) to improve the clarity, transparency and understanding of NDCs and to enhance tracking at global and national levels of NDC emission reduction targets and adaptation goals.

Addressing some knowledge gaps related to SOC will better support ambitious and transparent NDCs and action to protect and sequester SOC. Better estimates of countries' soil carbon potentials for protected soils and carbon sequestration will facilitate global priority setting and comparison against countries' commitments. Improved understanding of countries' capacities and motivations for not including SOC in their NDCs will help to better target capacity building. Enhanced data and measurement, reporting and verification systems will help countries overcome accounting constraints and could support harmonization to enable comparison and monitoring among countries.

In subsequent rounds of NDCs, better specification of SOC in the NDC may be especially relevant for countries or UNFCCC parties with the highest potential to sequester or protect SOC in pursuit of the 1.5°C or 2°C policy targets of the Paris Agreement. Improving specification in the ten countries with the highest soil carbon protection potentials would already provide transparency for 61% of the 600 Gt carbon stored in global peatlands. For the ten countries with the highest soil carbon sequestration potentials, improved specification would provide further transparency for 21% of the maximum 8.6 Gt CO_2eq of annual soil carbon sequestration potential in mineral soils. However, even countries with lower potentials may choose to specify SOC in NDCs to leverage climate finance, technical support, or capacity building for SOC-related policies and actions.

Guidance from the UNFCCC on the specification of sectors and subsectors, co-benefits to be included in NDCs, and the required level of detail for countries' mitigation and adaptation efforts on SOC measures and practices across related sectors and sub-sectors, would support such transparency and improved information, and ensure that no important potential for action is left untapped.

Notes

1. RothC = Rothamsted carbon model
2. DNDC-Rice = DeNitrification-DeComposition model for rice production

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ORCID

Liesl Wiese http://orcid.org/0000-0001-5835-4088
Susanna Esther Hönle http://orcid.org/0000-0001-5731-7170

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