



The Nationally Determined Contribution Expert Tool (NEXT): A Comprehensive Greenhouse Gas Accounting Tool to Support Annual Environmental Impact Assessment Over a 30-Year Time Series in the Agriculture, Forestry and Other Land Use Sector

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The Nationally Determined Contribution Expert Tool (NEXT) is a greenhouse gas accounting tool developed by the Food and Agriculture Organization of the United Nations (FAO) to support annual environmental impact assessment for the Agriculture, Forestry and Other Land Use sector (AFOLU). It provides a 30-year time series of annual and cumulated estimates of carbon removal and greenhouse gas emission reductions from actions determined by Parties in their climate policies. NEXT was developed using the Intergovernmental Panel on Climate Change (IPCC) methodologies, and estimates can be made using either the IPCC 2006 guidelines or the IPCC 2019 refinement to the IPCC 2006 which are both complemented with the IPCC 2013 Wetlands Supplement. The tool was designed to provide results that directly respond to the provisions of the Enhanced Transparency Framework and support the Nationally Determined Contributions (NDC) development as required by the modalities, procedures and guidelines. NEXT provides a detailed temporal series of results and a wide set of indicators, including the social value of carbon, enabling a comprehensive environmental and economic overview of climate actions in achieving mitigation targets. The tool helps countries to interpret, track and scale up ambition of their NDCs which could ultimately inform the global stocktake of the Paris Agreement in a harmonized way.

Keywords: Paris Agreement, Nationally Determined Contribution (NDC), long-term strategy, GHG accounting, AFOLU, climate change mitigation, Rio Conventions, social value of carbon

INTRODUCTION

In 2015, at the 21st Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC), the adoption of the Paris Agreement (PA) brought together developed and developing nations in a common cause to undertake ambitious efforts to combat climate change and adapt to its effects. Based on their national circumstances, priorities and historical responsibilities, each Party made a commitment to address its national greenhouse gas (GHG) emissions, possibly from all economic sectors, enhance removals, and adapt to the impacts of climate change as part of a global effort to tackle climate change. Their commitments are engraved in the Nationally Determined Contributions (NDCs) which have to be revised and strengthened every 5 years starting from 2020 on the basis of their respective mitigation and adaptation plans (article 4.3 of the PA). NDCs are one element of reporting to the UNFCCC, under the Enhanced Transparency Framework (ETF), which was designed to “provide a clear understanding of climate actions in the light of the objective of the Convention [...] including clarity and tracking of progress toward achieving Parties’ NDC [...], and Parties’ adaptation actions under Article 7, including good practices, priorities, needs and gaps, to inform the global stocktake under Article 14”, (article 13, paragraph 5). The ETF arrangements include “national communications, biennial reports and biennial update reports, international assessment and review and international consultation and analysis” (article 13, paragraph 4), which are submitted to the UNFCCC every 2 to 5 years according to their cycle and national capacities. To better frame the efforts toward the long-term goal, the PA encouraged countries to formulate their long-term low greenhouse gas emission development strategies (LT-LEDS) (Article 4, paragraph 19) (UNFCCC, 2022a). LT-LEDS provide the long-term horizon for NDCs, but unlike NDCs, they are not mandatory.

While extreme climatic events around the world are increasingly causing crop failure, dramatic human losses, displacement of thousands of people and severe economic losses (IPCC, 2022), global GHG emissions have been rising since 2015 despite strengthened international efforts. In 2018, the report from the Intergovernmental Panel on Climate Change (IPCC) on 1.5°C (IPCC, 2018) was a stark warning that global GHG emissions need to reach net-zero by 2050 to avoid catastrophic impacts from climate change. With the first part of the 6th assessment report (IPCC, 2021) published before the COP 26 in Glasgow, the IPCC warned of a red code for humanity. The Earth’s surface has already warmed by 1.1°C compared to pre-industrial levels, and unless immediate, rapid and large-scale reductions in GHG emissions are undertaken, the goal to limit global warming to 2°C, let alone 1.5°C, will be beyond reach.

In 2021, Parties were invited to submit their revised and enhanced NDCs. Yet, the new set of mitigation pledges, expressed as unconditional and conditional contributions, is seen as insufficient to achieve the GHG emission reductions objectives by 2030 and the PA’s temperature goals by mid-century (UNEP, 2021; UNFCCC, 2021). Current GHG emissions are 13.7 percent above 2010 levels (UNFCCC, 2022b) and new unconditional

contributions would only lead to an emission reduction of 7.5 percent in 2030, which is far off the 30 percent and 55 percent needed for 2 and 1.5°C, respectively (UNEP, 2021). The Glasgow Climate Pact adopted by the COP26 stressed “the urgency of enhancing ambition and action in relation to mitigation, adaptation and finance in this critical decade to address the gaps in the implementation of the goals of the Paris Agreement” and requested “[...] Parties to revisit and strengthen the 2030 targets in their nationally determined contributions as necessary to align with the Paris Agreement temperature goal by the end of 2022, taking into account different national circumstances” (UNFCCC, 2022c).

To avoid any worst-case scenario before 2050, the world must be able to estimate its GHG emission reductions strategies using a strong and possibly harmonized GHG accounting methodology where the path of each GHG fluxes can be tracked at least until 2050 (UNFCCC, 2022a). By doing so governments, International Financial Institutions (IFIs), private sector and civil society will have the necessary information to develop appropriate responses, policies, financial incentives and behavior changes.

The scientific community already developed tens of GHG accounting tools covering the Agriculture, Forestry and Other Land Use (AFOLU) sector. Most of them have been designed to serve a specific purpose, i.e., food value chains, carbon footprint of a commodity, project evaluation, sustainable land management, the resource impact of an organization, a region or a country (see reviews by Deneff et al., 2012; Milne et al., 2012; Colomb et al., 2013; Toudert et al., 2018). These tools are usually used by IFIs and Multilateral Development Banks (MDBs) either in ex-ante assessments to raise awareness or to help select climate strategies along with their economic and financial potential; or in ex-post assessments to estimate GHG emission reductions from the implemented climate strategies. Their main output is a carbon balance, which is the difference between a scenario considering the implementation of a climate strategy and its counterfactual, or a carbon footprint, over a given period, usually 20 years which is “the time period assumed for carbon stocks to come to equilibrium” (Chapter 2 volume 4, Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories 2006 the Refinement to the 2006 IPCC). The existing GHG accounting tools use these carbon balances or footprints to derive an annual average of GHG emission reductions. Yet, the international climate commitments require Parties to track climate ambitions and associated GHG emission reductions over time. The PA established key milestones such as the biennial update and transparency reports (to be submitted every 2 years starting from 2024), the national communications (to be submitted every 4 years) and the NDCs (to be submitted every 5 years). These reporting requirements call for a shift toward the estimation of annual GHG emission reductions of implemented climate actions. This will enable stakeholders to make more informed decisions and adequately plan the near, medium and long-term policy and investment necessary to maintain the PA’s temperature goal and to develop solid requests for additional international financial support to the AFOLU sector.

Climate finance is a fundamental element of the global development agenda and has been accelerating in the past years as recently quantified by FAO (Buto et al., 2021a,b), reaching USD 79 billion in 2019 (Buto et al., 2021b). However, the analysis identified that between 2000 and 2018 the share of global climate finance in the agriculture and land use sector decreased, passing from an average of 45% of the total flows at the beginning of the millennium, to 24% in 2013 where it has remained since (Buto et al., 2021a). In 2019, USD 18.4 billion, or 23% of climate finance was allocated to the agriculture and land use sector (Buto et al., 2021b).

Recognizing the pressing need for a tailored and standardized approach to estimate and track the low-carbon transition of the AFOLU sector in the context of the NDC and LT-LEDS, and in line with the transparency framework, the Food and Agriculture Organization of the United Nations (FAO) developed the NDC Expert Tool (NEXT). NEXT was designed to support government, national experts, and practitioners to estimate and track their ambitions in the AFOLU sector, and eventually revise their climate goals to meet national and international commitments made under the PA. NEXT is the first tool to propose a detailed time-series approach on GHG emissions and carbon stock changes over 30 years, enabling the estimation of carbon stock changes and GHG emissions on an annual basis. Practitioners in the AFOLU sector can therefore measure, oversee and plan their climate change mitigation actions in this sector and their contribution to achieve economy-wide carbon neutrality.

MATERIALS AND METHODS

NEXT is a comprehensive GHG accounting tool to assess national and subnational GHG emission reduction and carbon removals of actions and policies. The tool estimates annual carbon stock changes per unit of land (in hectare, ha), and emissions of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O), all expressed in metric tons of carbon dioxide equivalent per year (tCO₂e/year). The main output of the tool is the annual, and cumulated, estimation of the potential changes in GHG emissions from a set of climate actions against their counterfactual scenarios over a 30-year reading framework.

NEXT aligns with the ETF requirements and its modalities, procedures and guidelines (MPGs) II on “national inventory report of anthropogenic emissions by sources and removals by sink of greenhouse gases (GHGs)” and MPG III on “tracking progress of implementation and achievement of NDC under Article 4 of the Paris Agreement”.

NEXT's General Concept

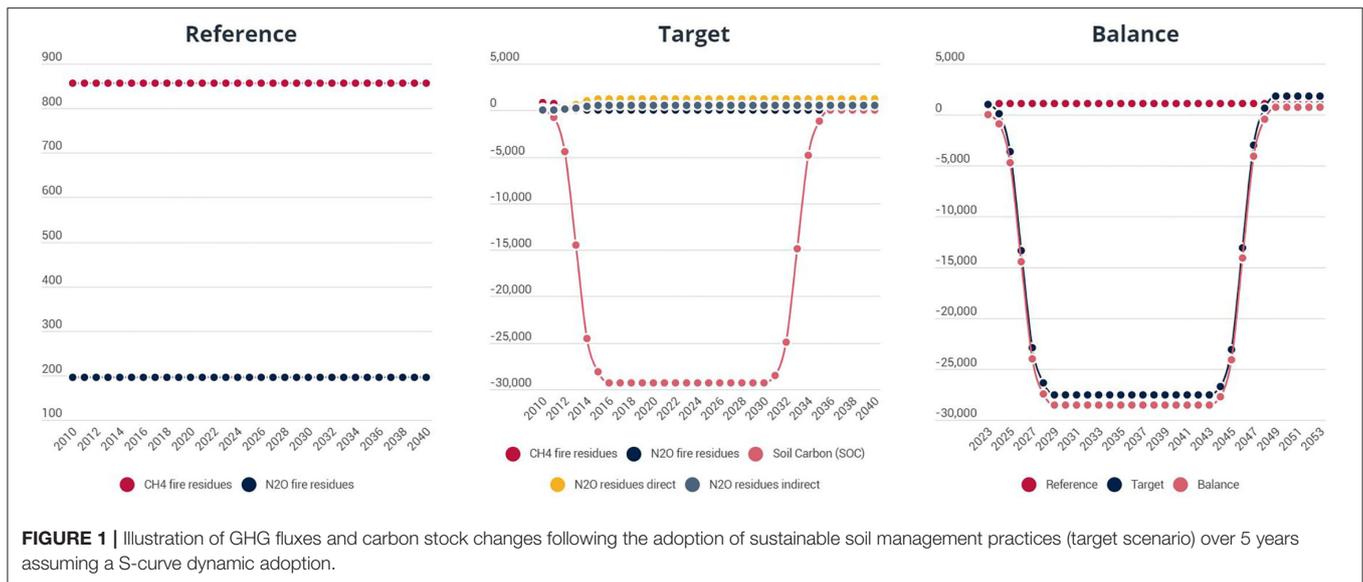
NEXT is an excel-based tool and comprises nine modules as described in **Table 1**. The tool includes a “Home” module, six modules on the different components of the AFOLU sector, a results module, and a “Help” module with different maps and national characteristics. NEXT estimates the climate change mitigation potential of implemented climate actions over a 30-year period compared to a counterfactual or reference scenario. The climate action or target under NEXT's terminology, can

TABLE 1 | NEXT components and associated activities.

NEXT's components	Activities covered by the component
Home	Set up phase of the tool Selection of the country, IPCC methodologies and global warming potential, timeframe of the reading grid
Forest land	Deforestation Afforestation/Reforestation Forest management
Cropland & Grassland	Cropland, grassland, settlement, other land and flooded land (as final land use) management
Wetlands	Peatlands Coastal wetlands Flooded lands
Livestock	Enteric fermentation Manure management
Nutrient	N-based nutrient and, lime, dolomite and urea management
HWP	Harvested wood product and their final use
Results	Broken down as a dashboard, a summary results of the GHG under the reference and target scenarios and the resulting balance, and 6 additional worksheets on the cumulated and annual GHG emissions for the reference, target and the balance, per activities and per gases
Help	Climate map, ecological zones map, soil map and soil carbon stock helper

be a policy or a measure, a Nationally Appropriate Mitigation Action (NAMA), a component of a LT-LEDS among other low-carbon measures implemented within the country. The reference scenario refers to scenarios based on the assumption that no mitigation policies or measures will be implemented beyond those already in force or planned to be adopted. The reference scenario is not a prediction of the future, but rather a counterfactual projection based on information retained as indicative of what the level of emissions could be without any mitigation policy. The term reference scenario can be used interchangeably with baseline or no policy scenario and can take the form of a business-as-usual (BAU) scenario.

NEXT estimates GHG emissions and carbon removals from basic information provided for each action in the respective modules. The main input data are the area in ha (or quantity of agricultural inputs, or the number of heads for livestock), the start and end year of the climate action, and the associated climate and soil type. In the case of land management, additional data is required on the soil management practices, the residue management, and the water table for organic soils, if applicable. Based on these information inputs, NEXT estimates the annual and cumulated GHG fluxes and carbon stock changes from (i) the initial land management practices, (ii) the transition to the initial land use or management practices to the final land use or management practices, and (iii) the final land use and associated management practices until the last converted area reaches equilibrium (**Figure 1**). These computations are performed to



provide cumulated and annual GHG emissions for the target, the reference scenario and the balance (see **Figure 2**). NEXT also provides highly disaggregated results on GHG emissions per scenario, per activities, per gas, per gas per activities and per gas per scenarios, per pools and GHG fluxes categories and per scenarios.

Methodologies

NEXT was developed using the Intergovernmental Panel on Climate Change (IPCC) Guidelines for National Greenhouse Gas Inventories 2006 (IPCC, 2006), the 2013 Supplement to the 2006 IPCC (IPCC, 2013), and the Refinement to the 2006 IPCC (IPCC, 2019a).

The main entry point in NEXT is the country. Once it is defined, NEXT is tailored for several national key parameters of which: the annual crops and livestock categories both retrieved from FAOSTAT (FAO, 2021), the associated climate from IPCC (2019a) revised after Audebert et al. (2021a,b), the soil types according to the Harmonized World Soils Database (HWSD) (Batjes, 2010) and the global ecological zones, (FAO, 2012). The perennial agroforestry and perennial monoculture are disaggregated at regional level according to Cardinael et al. (2018).

The tool offers the possibility to use either the IPCC (2006) or IPCC (2019a) methodology both complemented with IPCC (2013). The IPCC guidelines provide recommendations on methods and default estimates for assessing carbon stock changes and GHG fluxes at three tiers of details, from tier 1 up to tier 3. NEXT uses the tier 1 methodological approach and its associated and default emission and carbon stock changes factors, but allows to use tier 2 factors if users have the necessary data.

NEXT is based on the six broad land categories proposed by the IPCC when reporting on GHG inventories, i.e., forest land, cropland, grassland, wetlands, settlement and other land. Some categories include sub-categories describing specific characteristics that may have significant impacts on

the estimation of GHG emissions and carbon sequestration, such as settlement which can be disaggregated into settlement–settlement, settlement–cultivated areas, settlement–turf grass, settlement–urban green. Three approaches can be used to represent land use categories and areas, and conversions between land-use categories (IPCC, 2006, 2019a). NEXT retains approach 2 to track the conversions between land categories (i.e., not land sub-categories) over the 30-year period of analysis. The tracking of land use changes is performed on an annual basis for both the reference and target scenarios. The results are presented as a matrix of land use and land use change tracking.

Dynamics of Change in Land Use and or Management Practices

NEXT proposes different dynamics of implementation of the climate actions, i.e., linear, S-shaped or sigmoid curve, or exponential (**Figure 3**). A linear dynamic considers a constant annual implementation of the activities. The S-shaped curve considers a smooth implementation of the climate action, followed by a strong increase, before reaching the maximum of the action. The exponential dynamic considers a steep implementation of the climate action at its beginning before reaching a “plateau” by its end.

Generic Methodologies for Estimating Carbon Pool Changes

Chapters 2 of Volumes 4 of IPCC (2006) and IPCC (2019a) provide detailed information on generic methodologies. The generic methodologies are used principally to account for carbon stock changes and biomass burning during conversion between 2 categories. Carbon stock changes are addressed using the stock difference method for the 6 pools: above-ground biomass, below-ground biomass, soil, deadwood, litter and in some specific cases harvested wood product (HWP), see Equation 2.3 IPCC (2006) and IPCC (2019a).

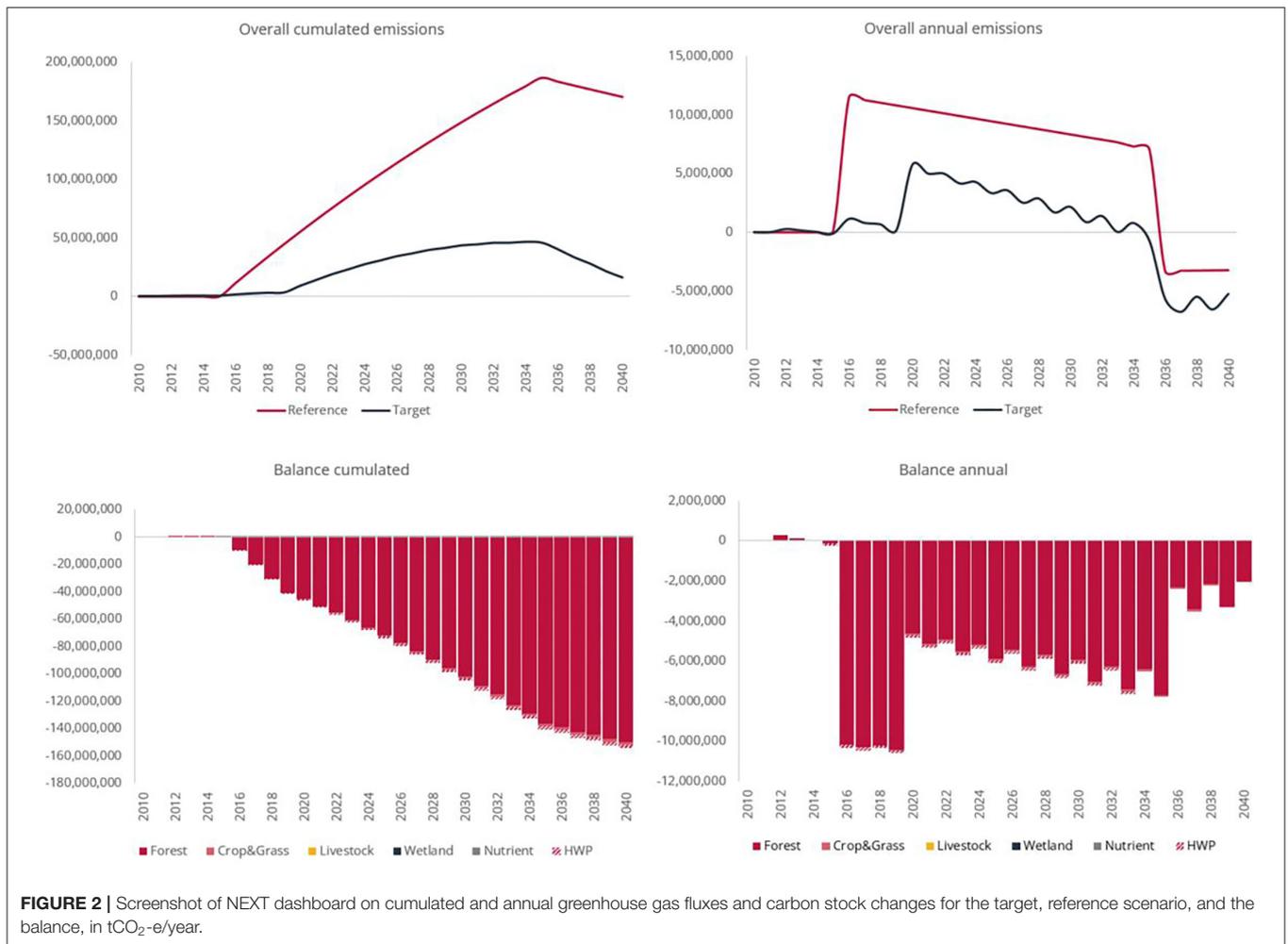


FIGURE 2 | Screenshot of NEXT dashboard on cumulated and annual greenhouse gas fluxes and carbon stock changes for the target, reference scenario, and the balance, in tCO₂-e/year.

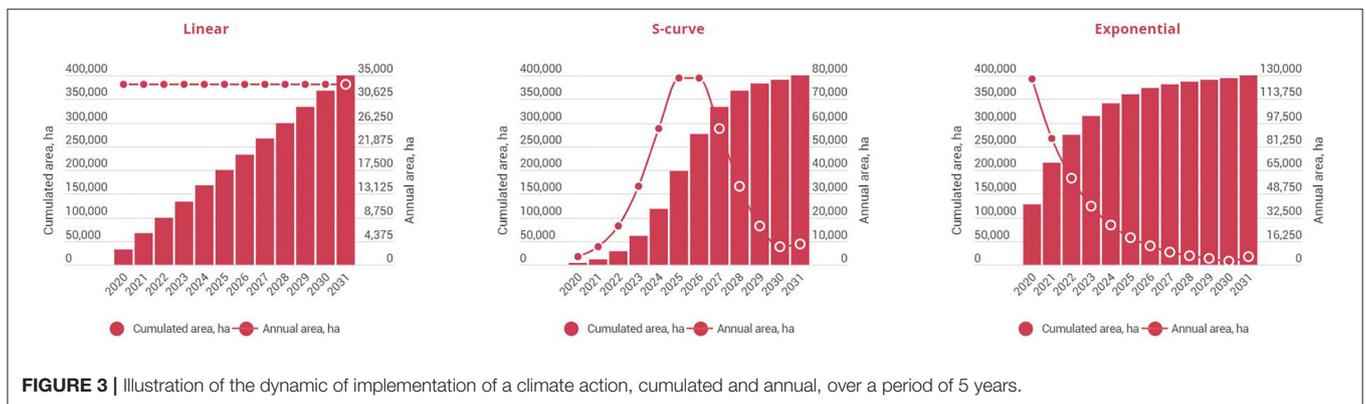


FIGURE 3 | Illustration of the dynamic of implementation of a climate action, cumulated and annual, over a period of 5 years.

Above-Ground Biomass

Default values for above-ground biomass (AGB) are estimates expressed in metric tons of dry matter per hectare (t d.m./ha), (IPCC, 2006, 2019a). The corresponding carbon stock, in metric ton of carbon per hectare (tC/ha) is calculated using the default carbon content, e.g. 0.47 for above-ground forest biomass (see Table 4.3, IPCC, 2006, 2019a) and 0.451 for mangrove forest

biomass (see Table 4.2, IPCC, 2013). These carbon stocks are referenced in each module.

Below-Ground Biomass

For forest and plantations, below-ground biomass is derived from the above-ground biomass using a root to shoot ratio of below-ground biomass to above-ground biomass (R) expressed

in metric ton root d.m./metric ton shoot d.m. The below-ground biomass is estimated only for natural forests and forest plantations and, when using the IPCC (2019a) methodologies, also for perennial agroforestry and perennial monoculture. R is additionally disaggregated between natural forests and forest plantations in IPCC (2019a), while this is not the case for the IPCC (2006).

Litter and Deadwood

The tier 1 approach assumes that litter and deadwood pools are zero in all non-forest categories. For mangroves carbon stocks in litter and deadwood are respectively 0.7 and 10.7 tC/ha (see Table 4.7, IPCC, 2013).

Mineral Soil Carbon

For the soil organic carbon (SOC) estimates, the default values are based on default references for soil organic carbon (SOC_{ref}) stocks for mineral soils to a depth of 30 cm (Table 2.3, IPCC, 2006, 2019a). When SOC changes over time, in case of land use change or changes in soil management practices, see Equation 2.25 IPCC (2006) and IPCC (2019a), a default time period of 20 years is assumed for transitions between equilibria. Some modules use carbon change rates instead of the SOC stock difference and therefore do not require information on absolute SOC stock.

The Harvested Wood Products

There are four approaches to account for the contribution of the HWP to the AFOLU sector: (i) the stock-change, (ii) the production, (iii) the atmospheric, and (iv) the simple decay approach (IPCC, 2006, 2019a). The stock-change and production approaches are based on a conceptual framework which focuses on carbon stock changes within defined HWP pools and deriving estimates of CO₂ emissions and removals from these. The atmospheric flow and simple decay approaches are based on a conceptual framework that focuses on identifying and tracking CO₂ fluxes (IPCC, 2006 and IPCC, 2019a). The stock-change and atmospheric-flow approaches cover stock changes or CO₂ fluxes associated within a consuming country, whereas the production and simple-decay approaches cover those associated with a producing country. NEXT retains the production approach, estimating changes in carbon stocks in the HWP pool consisting of products made from wood harvested in a given country, i.e., products that are consumed domestically and also products that are made in the country and later exported and used in other countries.

NEXT Carbon Stock Changes Estimates During a Land Use Change

The conversion to another land category or changes in land use management may be associated with a change of carbon from the biomass, the soil, and possibly litter and deadwood, and transfer of new biomass to the HWP pool. In the year of the conversion, NEXT assumes carbon stock of the initial land are at equilibrium, and that all this carbon will be lost and returned to the atmosphere if not transferred to the HWP. In the new land use, the carbon sequestered in the biomass, and the loss or gain of carbon in non-flooded soil is accounted for the year following

the conversion. The default values (tier 1) are available for each pool of each category (i.e., vegetation type) in the “Tier 2” section, which is to the right of the main module. The following equation describes the carbon stock changes occurring from 1 year to the next as a result of the conversion to another land use or changes in management practices in a given area.

$$\Delta C = (C_{t_{n+1}} - C_{t_n})_{initial} + (C_{t_{n+1}} - C_{t_n})_{final}$$

Where:

ΔC = the annual carbon stock change in the initial and final land use following a conversion to a new land use, in tC/ha,

C_{t_n} = the carbon stock in the pool at year n, in tC/ha, and

$C_{t_{n+1}}$ = the carbon stock in the pool at year n+1, in tC/ha.

Regardless of the period of implementation of climate actions, NEXT estimates carbon stock changes in the soil compartment over 20 years following changes in management practices and or land use changes on a given land and area.

All carbon stock changes, except for the harvested wood product, are converted into CO₂-e using a conversion factor of 44/12. A positive change from 1 year to the next will mean a loss of carbon stock and thus CO₂ emissions would be returned to the atmosphere. A negative carbon stock change will correspond to carbon sequestration and carbon removal from the atmosphere.

Generic Methodologies for Estimating GHG Fluxes

Biomass burning (*via* crop residues, conversion to a new land use, forest disturbances such as wildfire and insects), enteric fermentation, rewetting of inland wetland mineral soils (IWMS), aquaculture, soil management, land use change, water quality management, among others, are significant sources of CH₄ and N₂O emissions. For these emissions, NEXT adopted the generic approach as proposed in IPCC, which considers a simple multiplication of activity data with the emission factor for CH₄ and N₂O (Equation 2.6 IPCC, 2006 and IPCC, 2019a). Emissions from N₂O and CH₄ are then converted to CO₂-e using their global warming potential over a 100-year horizon from the IPCC Fifth Assessment Report, AR5 (Myhre et al., 2013) (Table 2).

Table 3 also provides the mapping of all the activities and associated GHG emissions and carbon removals associated to the different NEXT modules. A more thorough description of the methodologies used in NEXT is provided in its technical guidance (Schiettecatte, 2022).

RESULTS

NEXT has been tested on several case studies, ranging from intended NDCs (iNDCs) to LT-LEDS and investments in

TABLE 2 | Global warming potential over 100-years horizon for CH₄ and N₂O.

	AR5 with climate-carbon feedback	AR5 without climate-carbon feedback
CH ₄	34	28
N ₂ O	298	265

TABLE 3 | Mapping of the different greenhouse gas and their sources in the different NEXT modules.

Module	Activities	CO ₂	CH ₄	N ₂ O
Forest land	Deforestation	Initial land: N/A Final land: Carbon stock changes in biomass, litter and deadwood from conversion Carbon stock changes in soil from conversion and adoption of soil management practices for the new land	Initial land: N/A Final land: Emissions from fire from the conversion Emissions from residues burning if adopted Emissions of flooded rice if new land use Emissions from rewetting if any of inland wetland mineral soils	Initial land: N/A Final land: Emissions from fire from the conversion Emissions from residues burning if adopted Direct emissions from mineralization of soil following conversion Indirect emissions (leaching) from mineralization of soil following conversion Direct emissions from crop residues if left, retained or incorporated into the soils Indirect emissions (leaching) from crop residues if left, retained or incorporated into the soils
	Afforestation / Reforestation	Initial land: N/A Final land: Carbon stock changes in biomass, litter and deadwood from conversion Harvested wood product (HWP) if plantations in rotation Carbon stock changes in soil from conversion and adoption of soil management practices for the new land	Initial land: Emissions of flooded rice if initial land use Emissions from residues burning if adopted Final land: Emissions from fire from the conversion Emissions from rewetting if any of inland wetland mineral soils	Initial land: Emissions from residues burning if adopted Direct emissions from crop residues if left, retained or incorporated into the soils Indirect emissions (leaching) from crop residues if left, retained or incorporated into the soils Final land: Emissions from fire from the conversion Direct emissions from mineralization of soil following conversion (at tier 1 this is the case if the initial land use is flooded rice) Indirect emissions (leaching) from mineralization of soil following conversion (at tier 1 this is the case of the initial land use if flooded rice)
	Forest management	Initial land: CO ₂ emissions from disturbances, e.g. fires and insects Carbon transfer to HWP Final land: Carbon stock changes from management practices CO ₂ emissions from disturbances, e.g. fires and insects Carbon transfer to HWP Carbon sequestration from biomass regrowth	Initial land: CH ₄ emissions from fire disturbances Final land: CH ₄ emissions from fire disturbances	Initial land: N ₂ O emissions from fire disturbances Final land: N ₂ O emissions from fire disturbances
Cropland & grassland	Changes of management on soil, biomass, conversion to another land use, rewetting on inland wetland mineral soil	Initial land: N/A Final land: Carbon stock changes in biomass from conversion HWP if plantations or perennial systems in rotation Carbon stock changes in soil from conversion and adoption of soil management practices for the new land Emissions from flooded land reservoirs if final land use* Emissions from inland wetland mineral soils that are assumed previously dry and are still used as croplands.	Initial land: Emissions from flooded rice if initial land use Emissions from residues burning if adopted Final land: Emissions from flooded rice if final land use Emissions from flooded land reservoirs if final use* Emissions from residues or biomass burning if adopted Emissions from fire from the conversion Emissions from rewetting if any of inland wetland mineral soils	Initial land: Emissions from residues burning if adopted Direct emissions from crop residues if left, retained or incorporated into the soils Indirect emissions (leaching) from crop residues if left, retained or incorporated into the soils Final land: Emissions from residues or biomass burning if adopted Direct emissions from crop residues if left, retained or incorporated into the soils Indirect emissions (leaching) from crop residues if left, retained or incorporated into the soils Direct emissions from mineralization of soil following conversion Indirect emission (leaching) from soil mineralization Emissions from fire from the conversion

(Continued)

TABLE 3 | Continued

Module	Activities	CO ₂	CH ₄	N ₂ O
Wetlands	Peatland with land use changes, water table management such as drainage and rewetting	<p>Initial land: Emissions from drainage (CO₂ and DOC) Off-site emissions from peat extraction Emissions from fire on organic soils</p> <p>Final land: Carbon stock changes in biomass from conversion HWP if plantations or perennial systems in rotation Emissions from drainage (CO₂ and DOC) Off-site emissions from peat extraction Emissions from fire on organic soils Emissions from rewetting (CO₂ and DOC)</p>	<p>Initial land: Emissions from flooded rice if selected as initial land use Emissions from drainage (soil and ditches) Emissions from fire on organic soils Emissions from residues burning</p> <p>Final land: Emissions from flooded rice if selected as initial land use Emissions from drainage (soil and ditches) Emissions from fire on organic soils Emissions from residues burning Emissions from rewetting</p>	<p>Initial land: Emissions from drainage Emissions from residues burning Direct emissions from residues if retained or incorporated into the soils Indirect emissions (leaching) from residues if retained or incorporated into soils</p> <p>Final land: Emissions from drainage Emissions from residues burning Direct emissions from residues if retained or incorporated into the soils Indirect emissions (leaching) from residues if retained or incorporated into soils Emissions from rewetting</p>
	Coastal wetlands with water table management, aquaculture, and *water quality management	<p>Initial land: Emissions from drainage (CO₂)</p> <p>Final land: Carbon stock changes in biomass from conversion Emissions from drainage (CO₂) Emissions from rewetting</p>	<p>Initial land: Emissions from aquaculture</p> <p>Final land: Emissions from ponds Emissions from rewetting</p>	<p>Initial land: Emissions from aquaculture</p> <p>Final land: Emissions from aquaculture</p>
	*Flooded lands with water quality management	<p>Initial land: N/A Final land: N/A</p>	<p>Initial land: Emissions according to the trophic state</p> <p>Final land: N/A Emissions according to the trophic state</p>	<p>Initial land: N/A Final land: N/A</p>
Livestock	Enteric fermentation and manure management	N/A	<p>Emissions from enteric fermentation Emissions from manure management</p>	<p>Direct emissions from manure management Indirect emissions from manure management (volatilization and leaching)</p>
Agr. inputs	Fertilizers, urea and limestone	Emissions from urea application on managed soils	N/A	<p>Direct emissions from N-based fertilizers Indirect emissions from N-based fertilizers (volatilization and leaching)</p>

*Only if users selected IPCC (2019a) and IPCC (2013) in NEXT's "Home" menu.

sustainable land management. The following case study is an analysis of relevant AFOLU sections of Ghana's iNDC submitted in 2015 (UNFCCC, 2022d), and complemented with data from national documentation of different ministries, communications submitted to the UNFCCC, and relevant publications.

Despite significant improvements in the second NDC submitted in 2021, notably the inclusion of 14 additional policy activities related to mitigation (with no further description), a revision of the GHG emissions baseline, a change of the base year, and the GHG emission reductions targeted, the level of information was insufficient to run a climate change mitigation analysis with this updated NDC.

iNDC Description

Ghana's iNDC entails 31 NDC actions, of which 11 are related to adaptation and 20 are related to mitigation. It covers 7 priority areas: energy, transport, agriculture, water and climate services, industry, health and forestry. The 2010 baseline GHG emissions is derived from the 1990–2012 time series and the GWP over a 100-year horizon used are 21 for CH₄ and 310 for N₂O. Ghana set

an unconditional target of reducing its national GHG emissions by 12% in 2025 to reach a 15% reduction by 2030. Under the guarantee of international financial support (conditional), Ghana's overall mitigation reduction goal is to lower its GHG emissions by 45% relative to a business as usual (BAU) scenario, corresponding to about −74 million tCO₂-e by 2030. These targets translate into −33.3 million tCO₂-e between 2020 and 2030, i.e., −11 million tCO₂-e unconditional and −22.2 million tCO₂-e conditional emissions reduction (Table 4) (UNFCCC, 2022d).

Whilst Ghana did not specify a specific target in the agriculture, forestry, land use and land-use change (LULUCF) sector (now referred to as AFOLU), the country identifies five programmes of action in the AFOLU sector, and two in the energy and waste sectors with climate co-benefits for AFOLU (see Table 5). Four AFOLU actions are focusing at the forestry sector where the abatement potential is higher. Ghana aims to reduce forest degradation and deforestation, which are posing significant threat to the livelihoods of forest fringe communities, ecosystem services and the country's agrarian economy. Deforestation

TABLE 4 | Ghana's baseline of 2015 NDC commitments and contribution of the climate actions analyzed in the present study.

Target year	2010	2020	2025	2030
GHG emissions Base year	19.5			
Reference (BAU all sectors) level		37.8	53.5	74.0
AFOLU reference		10.6	9.4	8.3
Percentage unconditional reduction target (all sectors)			12%	15%
Target GHG		37.8	47.1	62.9
AFOLU Unconditional (reference–unconditional)		10.6	9.4	8.3
Contribution of AFOLU to unconditional reduction			0%	0%
Percentage conditional reduction target (all sectors)			27%	45%
Target GHG		37.8	39.1	40.7
AFOLU conditional (reference–conditional)		6.4	4.5	3.8
Contribution of AFOLU to conditional reduction			34%	14%

and forest degradation are currently reaching 135,000 ha per year, and are primarily driven by agricultural expansion (e.g., cocoa expansion, tree crops among others), wood harvesting, population and development pressures, and mining and mineral exploitation (FAO, 2022). In addition, the production of compost from waste and the use of more efficient cook stoves help to reduce the use of synthetic fertilizers and fuelwood consumption and have other environmental benefits.

Country's Profile

Ghana is situated in West Africa at the Guinea Coast, and is subdivided into 3 distinct global ecological zones: tropical dry forest, tropical moist deciduous forest and tropical rainforest (Figure 4). Ghana's climate is mainly tropical, dry in its northern part and moist in the vast majority of the country. The soil is mainly a low activity clay soil (LAC) and a mix of LAC and high activity clay soils (LAC/HAC) (Figure 5).

Climate Change Mitigation Actions

NEXT is configured with the IPCC (2019a) methodologies for Ghana's policy and measures (P&Ms) analysis as it is a recommended source of default emission factors and carbon stock in the Forest reference Level (FREL) (Forestry Commission, 2022a). The GWP are from the 5th AR with climate-carbon feedback, i.e., 34 for CH₄ and 298 for N₂O. The period of analysis spans from 2010 to 2040. The objectives and active period of P&Ms at the core of the mitigation actions are listed in Table 6. When the period of implementation of the climate action was not specified, the active period of their associated P&M was used instead. Default stocks (tier 1) replaced with national data (tier 2) are presented in Table 7.

Unconditional Climate Change Mitigation Actions

Afforestation/Reforestation

The unconditional mitigation action is laid out in the 2012 national Forest and Wildlife Policy (NFWP), the Ghana Forest Plantation strategy (GFPS), and the REDD+ strategy which aimed at increasing forest cover among other goals. As part of this, in its iNDC, the Government of Ghana (GoG) committed

to continue to reforest/afforest “10,000 ha of degraded lands” annually, as described in the Forestry Development Master Plan (Forestry Commission, 2022b) (see policy action M1 in Table 6). In the analysis, it was assumed that most of the reforestation activities were implemented in the southern part of the country, dominated by a tropical moist climate and LAC soil, with a period of implementation spanning from 2012 to 2036. Two types of initial land were considered, cropland set-aside and grassland managed by high intensity grazing. A survival rate of replanted forest of 75% was used (Forestry Commission, 2022c), which led to the removal of about –35 million tCO₂-e by 2040 from the implementation of this action.

Conditional Climate Change Mitigation Actions

With international financial support, the GoG planned to intensify the implementation of climate actions. For instance, the reforestation activities would double (see policy action M1 in Table 6) from 2016 leading to an additional 150,000 ha of forest, or about –25.7 million tCO₂-e additional removal by 2040, based on the same assumptions of the aforementioned action. In parallel, the REDD+ strategy aimed at supporting the “enhancement of forest carbon stock through enrichment planting and enforcement of timber felling standards” of “5,000 ha per year” (see policy action M2 in Table 6). In simple terms, this activity can be referred to as reforestation. Therefore the reforestation of 5,000 ha per year, starting from 2012 until 2036, would lead to an increase of forest areas by 90,000 ha (assuming a survival rate of 75 percent), and a carbon removal about –7 million tCO₂-e removal by 2040.

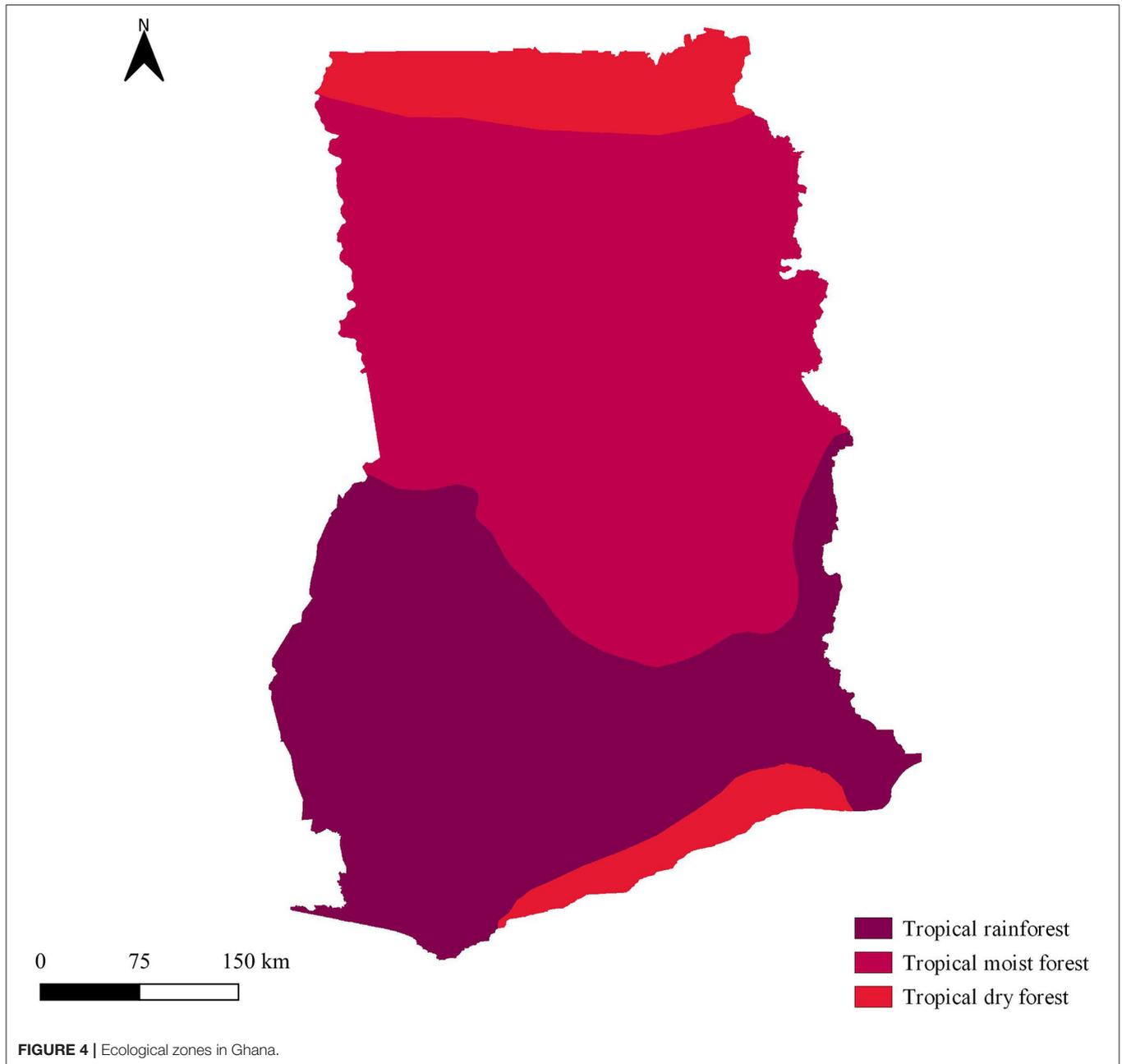
Deforestation

Cocoa production is one of the major drivers of deforestation in the south and south-west of the country. Ghana's REDD+ strategy aimed to reduce GHG emissions from deforestation and forest degradation, and enhance forest carbon stock through the implementation of several strategies including the “emission reductions programme for the cocoa forest mosaic landscape”. As stated in the REDD+ strategy, the emissions reduction (ER) program should be implemented over two periods, from 2016 to 2020 and from 2020 to 2036, see policy action M3 in Table 6. The second phase would depend on the potential buyers of emission reductions. Over the first period, GHG emissions were expected to decrease by about 20.5 million tCO₂-e. As input data in NEXT are predominantly in hectares, the GHG emissions target was translated into a quantifiable unit for the NEXT analysis. Using the deforestation rate of 2010, i.e., 18,183 ha, and the national carbon stocks for forest and cocoa plantations (Table 6), 72,372 ha of tropical forest are expected to be preserved from conversion into cocoa plantations which would reduce GHG emissions by 20.5 million tCO₂-e in 2040. The same approach was used to estimate the emission reductions from the second period of the cocoa strategy, which was expected to decrease GHG emissions by 45%. We estimated that without the ER program (reference scenario) about 272,745 ha of forest would have been lost, against 150,010 ha if the emissions reduction was fully implemented (target) over the period 2021–2036. This would lead to a decrease

TABLE 5 | Policy and measures reported in the intended nationally determined contribution of Ghana with benefits on climate change mitigation.

Sector	Policy actions	Supporting national policy and measures	Objectives	Start year	End year	Conditionality and programme of actions
LULUCF	M1–Reforestation Promote sustainable utilization of forests resources through REDD+	- REDD+ strategy	REDD+ strategy: seeks to significantly reduce emissions from deforestation and forest degradation from 2016 to 2036, whilst at the same time addressing threats that undermine ecosystem services and environmental integrity so as to maximize the co-benefits of the forests.	2016	2036	Unconditional: Continue 10,000 annual reforestation/afforestation of degraded lands (Forestry Development Master Plan). Conditional: Double the above actions, i.e., 20,000 ha/yr
		- 2012 National Forest and Wildlife Policy	2012 Forest and Wildlife Policy: aims at the conservation and sustainable development of forest and wildlife resources in Ghana. Implemented by the Forestry Development Master Plan 1996–2020.	2012		
		- Ghana Forest Plantation Strategy (GFPS)	Ghana Forest Plantation Strategy. Aims at achieving sustainable supply of planted forest goods and services to deliver a range of economic, social and environmental benefits over and beyond the planned period.	2016	2040	
LULUCF	M2 –2012 NFWP [Enhancement]	2012 National Forest and Wildlife Policy	2012 Forest and Wildlife Policy: See above.	2012		Conditional: Support enhancement of forest carbon stocks through 5,000 ha/yr enrichment planting and enforcement of timber felling standards
		Timber Resource Management Act	An Act to provide for the grant of timber rights in a manner that secures the sustainable management and utilization of the timber resources of Ghana and to provide for related purposes.	1997		
LULUCF	M3– National REDD+ Strategy [Cocoa landscape]	2012 National Forest and Wildlife Policy	2012 National Forest & Wildlife Policy: see above	2012		Conditional: 45 percent emission reduction of deforestation through result-based emission reduction programme in cocoa landscape
		National REDD+ Strategy	REDD+ strategy: see above	2016	2036	
LULUCF	M4–Wildfire strategy and REDD+	2012 National Forest and Wildlife Policy	See above	2012		Conditional: Wildfire managements in the transition and savannah drylands
		National REDD+ Strategy	See above	2016	2036	
Energy	M5–Energy package	Sustainable Energy For All Action Plan (SE4ALL)	Aims at (i) Achieving universal energy access, (ii). Doubling the global rate of improvement in energy efficiency; and (iii) Doubling the share of renewable energy in the global energy mix.	2015	2030	- Scale up adoption of LPG use from 5.5 percent to 50 percent peri-urban and rural households up to 2030 - Scale up access and adoption of 2 million efficient cook stoves up to 2030
Waste	M6–Waste package	-National sanitation strategy -National bioenergy strategy. -National renewable energy Act (Act 832) -Environmental Protection Act (Act 490) -Environmental Assessment Regulation (L.I. 1652) -Sustainable Energy Action Plan.	Aims at adopting alternative urban solid waste management	2015	2030	Conditional: Double the current waste to compost installed capacity of 180,000 t/yr by 2030.
Agriculture	A1–Agriculture resilience package	Food & Agriculture Sector Development Policy II	All policies aim at building resilience in climate vulnerable landscapes	2009	2015	Conditional: Modified community-based conservation agriculture adopted in 43 administrative districts
		Medium-Term Agriculture Sector Investment Plan [METASIP]		2014	2017	
		Agricultural Sector Investment Programme (IFAD project)		2016	2022	

The start and end year of the IFAD project were revisited accordingly to last updates available (IFAD, 2022).

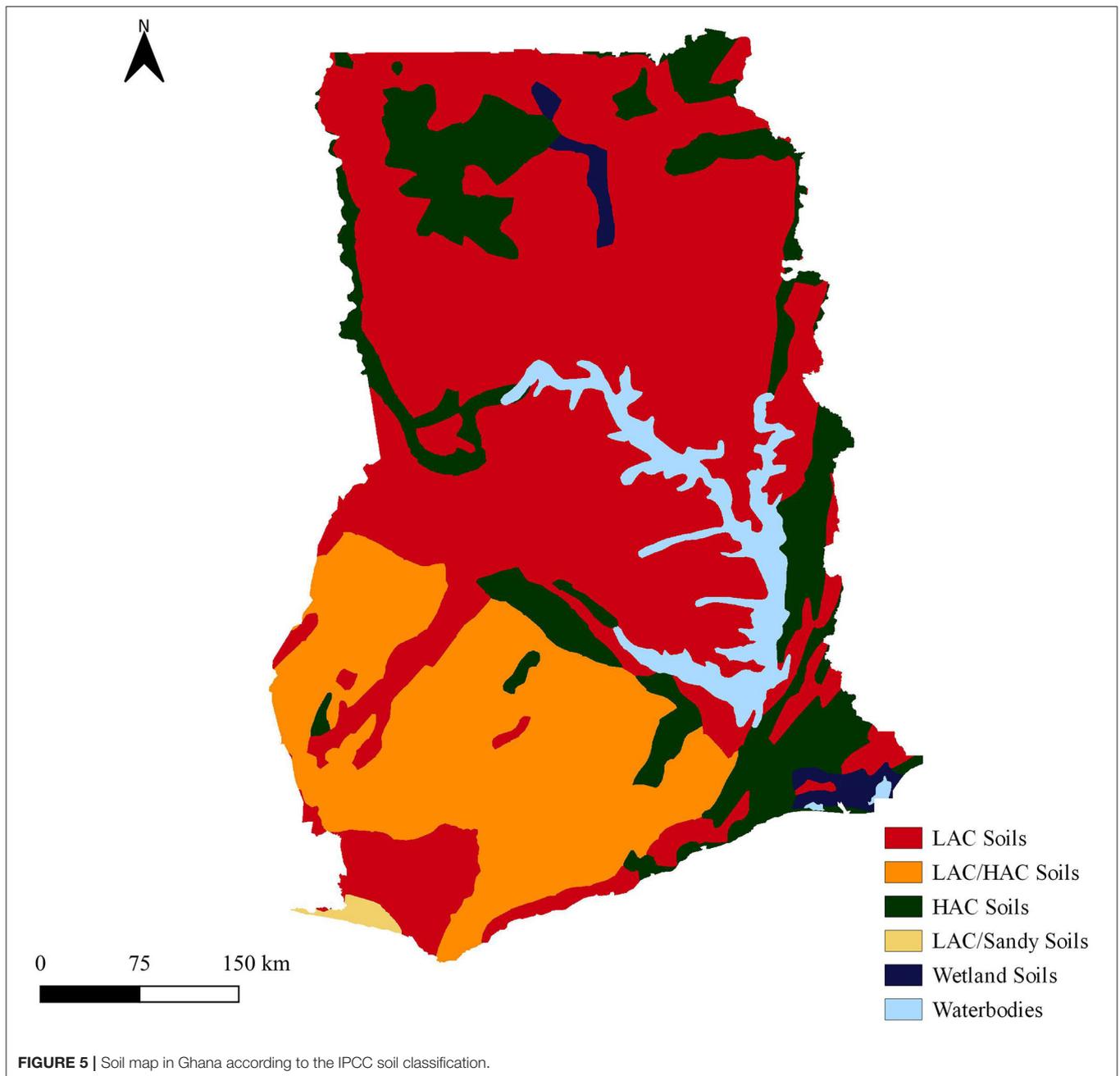


of GHG emissions from deforestation by about 52.7 million tCO₂-e in 2040.

Forest Management

Two climate actions were planned to preserve forest carbon stocks. The first one, the energy package (2015–2030), aimed at expanding the adoption of cleaner and more efficient cooking stoves, which would reduce fuelwood consumption and conservation of the forest for other productive uses. 39,500 ha of woodland (savanna) would thus be preserved from degradation, see climate action M5 in **Table 6**. Using the national carbon stock

of savanna, i.e., 36.53 td.m./ha, this mitigation action would help to reduce the GHG emissions by 2.6 million tCO₂-e by 2040. The second strategy, the Wildfire and REDD+ strategy (2016–2036), aimed to manage wildfire in the transition and savannah dry lands. The analysis focused on the area occupied by the dry semi-deciduous forest (fire zone), i.e., 816,347 ha (Forestry Commission, 2022c), and assumed that every year wildfire would affect 2% of this area. With implementation of the strategy, see climate action M4 in **Table 6**, the wildfire would only occur every 2 years in the same area and would help to reduce GHG emissions by about 9 million tCO₂-e by 2040.



Nutrient Management

The waste package aimed to double the amount of compost produced through better management of urban solid waste, in order to apply it to agricultural soils in place of synthetic fertilizers. Between 2015 and 2030, the quantity of compost was expected to increase from 90,000 to 180,000 metric tons per year, which translated into respectively 360 and 720 metric tons of nitrogen equivalent if we assume that 1 ton of compost contains about 2% of nitrogen (see climate action M6 in **Table 6**). 360 metric tons N-based compost should also be equivalent to about 51 metric tons of N-based fertilizer if we assume a 1/7 N-based ratio between the two fertilizers. While this activity is generating

GHG emissions (about 30,000 tCO₂-e by 2040), the shift from synthetic to organic fertilizers does have some additional benefits that are not quantifiable here, i.e., increase of SOC content, the reduction of GHG emissions from the waste sector and positive impacts on biodiversity. The change in SOC from application of compost was not estimated in the analysis as there are no information on the type of land where it is applied.

Cropland Management

The agriculture resilience package was one of the set of actions under climate change adaptation but with co-benefits for climate change mitigation. Several P&Ms were listed including the

TABLE 6 | Indicators derived from the analyzed policy and measures, description and assumptions taken for the target and reference scenarios.

Mitigation actions	Start year	End year	Indicator and indicator description	Description of the target scenario and assumptions taken	Description of the reference scenario and assumptions taken
M1—Reforestation Promote sustainable utilization of forests resources through REDD+	2012	2036	Cumulated area with increased afforestation/reforestation. By 2036, 330,000 ha of land are converted into forest.	[Unconditional] By 2036, moist semi-deciduous forest areas increase by 180,000 ha as compared to 2010. Assumption: the survival rate is 75 percent.	330,000 ha of grasslands managed with high intensity grazing and cropland set-aside remained unchanged. Remark: for the NEXT analysis, we chose cropland set-aside and grassland high intensity grazing as equivalent for degraded areas, since degraded areas are not an IPCC land use.
	2016	2036		[Conditional] by 2036, moist semi-deciduous forest areas increase by 150,000 ha as compared to 2010 in addition to the unconditional commitments. Assumption: the survival rate is 75 percent.	
M2—2012 NFWP [Enhancement]	2012	2036	Cumulated area with increased afforestation/reforestation. By 2036, including M1 and M2, forest areas increase by 420,000 ha.	[Conditional] By 2036, 90,000 ha of forest have enhanced carbon stock. Assumption: the survival rate is 75 percent.	Assumptions: the enhancement activities are taking place in the cleared area of open forest. For sake of simplicity we consider them as grassland with high intensity grazing. In the reference scenario, these grasslands remained unchanged.
M3—National REDD+ Strategy [Cocoa landscape]	2016	2036	Cumulated area with reduced deforestation and percentage of change in deforestation. Net zero deforestation is reached by 2036. By 2036, 203,650 ha of forest area preserved from deforestation.	[Conditional] 72,732 ha of moist semi-deciduous forest are preserved.	The REDD+ strategy anticipated it will avoid the GHG emissions of about 18.5 million tCO ₂ -e. Assuming the 2010 annual deforestation rate, 72,732 ha of moist semi-deciduous forest are cleared to grow cocoa plantations.
	2020	2036	By 2036 deforestation has decreased by 56%.	[Conditional] By 2036, the deforestation rate decreases by 45%. This translates into 160,010 ha of moist semi-deciduous forest converted into cocoa plantations between 2020 and 2036.	Taking as a reference the annual deforestation rate of year 2010, over the period 2020–2036, 290,928 ha of moist semi-deciduous forest are converted into cocoa plantations.
M4—Wildfire strategy and REDD+	2016	2036	Forest carbon stock preserved in fire prone areas (dry semi-deciduous forest, fire zone) of a total area of 816,347 ha.	[Conditional] Two percent of the area (dry semi-deciduous forest, fire zone) is affected by wildfire every two years.	Two percent of the area (dry semi-deciduous forest, fire zone) is affected by wildfire every years.
M5—Energy package	2015	2030	Area of woodland (savannah) and tons of fuelwood collected. By 2036, including M4 & M5, 855,847 ha of forest are preserved.	[Conditional] By 2030: 39,500 ha of woodlands (savannah) is saved from degradation by reducing fuelwood consumption	Within an area of 39,500 ha and an average of 17.2 tC/ha, about 36,235 tC/yr can be collected over the period of implementation to reach an equivalent of 80% degradation of the area.
M6—Waste package	2015	2030	Quantity of compost produced.	[Conditional] By 2030, 720 tons equivalent of compost are produced from waste and then applied on agricultural soil instead of N-based synthetic fertilizers. Assumptions: 1 ton of compost contains 2 percent of nitrogen. N ratio compost/n-based synthetic fertilizer is 2/15.	By 2030, only 360 tons equivalent of nitrogen fertilizers from compost are produced. Without the increased production of compost, we assume that about 103 tN-based synthetic fertilizer are still applied on agricultural soils. Assumption: 1 ton of compost contains 2 percent of nitrogen.
A1—Agriculture resilience package	2016	2022	Area of land (other than forest) under sustainable management practices, such as increased soil carbon stock. By 2022, 74,320 ha of land with increased SOC.	[Conditional] By 2022: –22,800 ha of cassava, 22,800 ha of maize and 17920 ha of sorghum under nutrient management, minimum tillage, and residues retained; –400 ha of maize and 400 ha of pineapples under irrigation, reduced tillage. Residues are retained for maize, and exported for pineapples; 5,000 ha of maize and 5,000 ha of soybean have shifted under crop rotation, nutrient management and minimum tillage. General assumption: the yield increases by 1.5 for all crops but pineapples.	Assumptions: 74,320 ha of annual crops are under full-tillage, low input. Agricultural residues are burned at the end of the cultivation period, except for pineapples residues, which are burned every 2 years.

TABLE 7 | National data used for the analysis.

Initial land				Final land			
Deforestation module	Tier 2	Unit	Reference FREL		Tier 2	Unit	Reference FREL
Moist semi deciduous—AGB	273.8	td.m./ha	Table 35	Cocoa AGB	2.54	tC/ha/yr	Table 22
Moist semi deciduous—BGB	49.4	td.m./ha	Table 27	Cocoa maturity cycle	30	years	Table 22
Reforestation module							
				Moist semi deciduous	4.19	td.m./ha/yr	Table 21
Forest management module							
HWP management in woodland (savanna)—AGB	36.53	td.m./ha	Table 35	Same as initial land			
Fire management in dry semi deciduous (fire zone)—AGB	40	td.m./ha	Table 35	Same as initial land			

All values are from the forest reference emissions level (Forestry Commission, 2022c). We assumed a carbon fraction of 0.47 (tC/td.m), IPCC (2019a).

agriculture sector investment programme. This programme aimed at building resilience in climate vulnerable areas. GHG emission reductions were estimated from the information available in the project design report (IFAD, 2014) (see climate action A1 in **Table 6**). Overall, on the targeted area of 74,320 ha, the shift from traditional agriculture (tillage, residues burning) to more sustainable practices, i.e. zero-tillage or reduced tillage, medium to high inputs and residues left on the field, would reduce GHG emissions by about 2 million tCO₂-e in 2040.

Overall Results

Cumulated and annual GHG emissions for the reference, target and associated balance are presented in **Figure 2**. This analysis covered an area of 1,713,827 ha across the country and spanned from 2010 to 2040, with the final year of the last planned activity ending in 2036. Cumulated GHG emissions in the reference scenario reached up to 180 million tCO₂-e in 2035 and were strongly dominated by deforestation and forest degradation. The decrease in cumulated GHG emissions came as a result of the carbon removal from the cocoa plantations, as also shown by the annual profile. Cumulated GHG emissions in the target scenario followed the same trend as the reference scenario with a maximum of about 46 million tCO₂-e by 2034. The anticipated peak in GHG emissions for the target scenario comes from the implementation of the different reforestation strategies, which then curb the emissions from deforestation. The end of deforestation further accelerates the drop in GHG emissions, with net-zero emissions potentially reached by 2035 *via* this analysis. By 2040, the GHG emission reduction from the P&Ms as compared to its counterfactual scenario amounts to approximately 150 million tCO₂-e.

More interestingly, annual GHG emissions for both scenarios show a decrease of GHG emissions from 2016 to 2036, due to the cocoa plantations, with a drop of the emissions when deforestation ends in 2036. The sinusoidal curve of the target scenario is explained by forest fire (wildfire) management shifting from every year to every second year, as illustrated by the annual forestry profile of CH₄, N₂O and CO₂. In other words, NEXT does not retain the principle of synchronicity for CO₂ emissions coming from forest fires (**Figure 6**). The share of CH₄ and N₂O

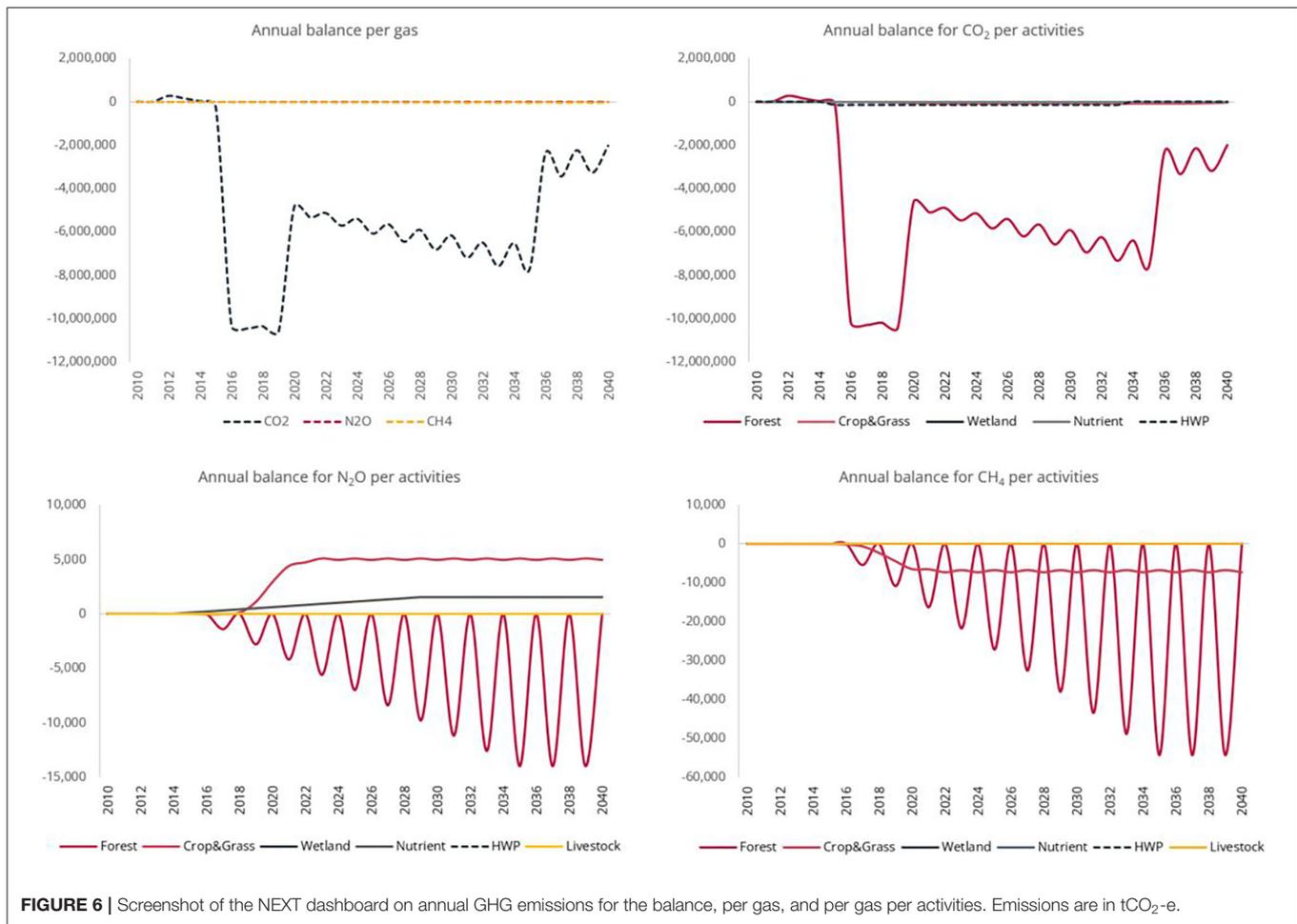
emissions in the total GHG emissions remained relatively small, down to two orders of magnitude lower than the CO₂ ones. Overall, the contribution of unconditional climate actions to the overall reference scenario was relatively small, while the conditional climate actions contribute to to 34% of the GHG emissions reduction targets by 2025 and 14% by 2030 (**Table 4**).

DISCUSSION

Land use activities (deforestation, land degradation, unsustainable agricultural management practices) are net contributors to GHG emissions. According to the IPCC Special Report on Climate Change and Land (IPCC, 2019b), the AFOLU sector contributes to ~23% of global anthropogenic emissions. These GHG emission shares represent up to one third of global GHG emissions when considering global food systems (Crippa et al., 2021). A growing global population combined with unsustainable practices, increased pressures on land and land use changes and cascading negative effects on the environment such as biodiversity loss, are putting the achievement of the Sustainable Development Goals (SDGs) and the PA objective of reaching net-zero emissions by mid-century in peril. Setting measurable and quantifiable GHG emission reductions targets are the stepping stones toward a sound decarbonisation strategy.

This tool provides a simplified yet comprehensive approach to address several challenges related to climate change mitigation analyses of the AFOLU sector: data availability, the formulation of the mitigation target (GHG target vs. non GHG target), the linkages between the different sectors, and the lack of harmonized methodologies in GHG accounting, in particular the GWP.

Climate change mitigation analyses are particularly challenging in the cropland and livestock sub-sectors, in particular when it comes to the data needed to quantify GHG emissions. For instance, the climate change mitigation potential for croplands holds in the soil carbon sequestration, which is estimated based on the knowledge of soil management practices, such as tillage and inputs, applied on a specific area. This information and the areas in which they are applied are therefore mandatory for the estimates of carbon removal by the soil. Flooded rice systems are even more complex as the



only mitigation option is to reduce CH₄ emissions. To quantify GHG emission reductions it is necessary to know the water table management practices prior and during cultivation and the organic amendments for flooded rice systems. This can become more complex when there are up to three different rice cultivation over an annual cycle as seen in Asia. This complexity of information might be the reason why these sub-sectors are still more covered in the climate change adaptation component than the mitigation one. In the second set of NDCs, the crop and livestock sub-sectors covered 51 and 36% of the mitigation component and 70 and 55% of the adaptation component respectively (Crumpler et al., 2021).

The other challenge is the weakness of the harmonized approach in the IPCC methodologies and metrics (GWP). In 2018, when drafting the ETF the CMA decided “Each Party shall use the 2006 IPCC, Guidelines, and shall use any subsequent version or refinement of the IPCC guidelines agreed upon by the Conference of the Parties serving as the meeting of the Parties to the Paris Agreement (CMA). Each Party is encouraged to use the 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands.” and “Each Party shall use the 100-year time-horizon global warming potential (GWP) values from the IPCC Fifth Assessment Report,

or 100-year time-horizon GWP values from a subsequent IPCC assessment report as agreed upon by the CMA, to report aggregate emissions and removals of GHGs, expressed in CO₂ eq” (UNFCCC, 2022e). NEXT encourages the adoption of above recommendations to countries who haven’t yet adopted the IPCC recommended methodologies.

Urgent and profound changes in our food systems need to take place to prevent temperatures rising and to adapt, mitigate and build resilience to climate change, limit damage to ecosystems, avoid displacement of human population and conflicts (Webb et al., 2020; FAO et al., 2021). Managing emissions in the food sector offers opportunities to break silos and focus on the nexus of agriculture, industry, waste and energy, bridging all actors, farmers, end-consumers, societies, private banks, governments and investors from all sectors. Numerous standards have been developed to support the private sector in the annual assessment and reporting of their GHG emissions reductions, from scope 1 to scope 3 emissions, such as the ISO 14064 family of standards (ISO, 2022) or the GHG protocol (GHG Protocol, 2022). Yet, to the best of our knowledge, such standards are not available to support Parties in the same exercises with their climate P&Ms. NEXT addresses these gaps by providing annual time series analyses of the climate change mitigation potential of

implemented and planned P&M of the AFOLU sector over a 30-years horizon.

This work presents the preliminary analysis of a set of climate mitigation actions submitted in an iNDC. Results showed the suitability and flexibility of NEXT in analyzing national P&Ms, implemented during different years and in different agro-ecological zones. In addition to the annual GHG emissions for the reference, target and balance, NEXT also provides a dashboard with a wide range of indicators for Parties and financial institutions to report on targets for specific years. These include the percentage of change of forest cover, percentage of change of deforestation, cumulated area with increased afforestation, cumulated areas with restored forest and cumulated areas with increase mineral soil organic carbon. Annual results in NEXT are further disaggregated by carbon pools (biomass, soil) and categories (flooded land, enteric fermentation, manure management among others) which provide a comprehensive understanding of sources and sinks of GHG associated to the AFOLU sector.

NEXT is an integral part of the NDC toolbox developed at FAO, which also includes the NDC tracking tool and the Adaptation, Biodiversity and Carbon Mapping (ABC-Map) Tool. The NDC tracking tool supports countries to track the implementation of NDCs, by comparing planned vs. P&Ms to the ones that are implemented mitigation actions to support for all sectors and comparing achieved emissions reduction from mitigation action against sectorial and/or national baseline and the NDC target scenarios. The tool also provides templates tailored to the set of information categories necessary for tracking the implementation and achieving NDCs according to the MPGs. The Adaptation, Biodiversity and Carbon Mapping (ABC-Map) tool is a new geospatial app based on Google Earth Engine (GEE) developed by FAO that holistically assesses the environmental impact of national policies and plans (NDC, National Adaptation Plan, etc.), and investments in the AFOLU sector. ABC-Map provides users with several indicators for baseline and project scenarios on climate change adaptation (including climate and geophysical profile), biodiversity (including mean species abundance, key biodiversity and protected areas, and natural capital) and climate change mitigation (including total carbon stock and social value of carbon). This new application thereby aligns with the objectives of the three Rio Conventions, the UNFCCC, the Convention on Biological Diversity (CBD) and the United Nations Convention to Combat Desertification (UNCCD).

CONCLUSION

At a time when Parties have been invited to revisit and enhance their 2nd NDC in order we can collectively manage to reduce

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the GHG emissions reduction gap, and at a time when only 50 out of 197 Parties submitted their LT-LEDS (UNFCCC, 2022f), the need to take stock, measure and plan strategies to reduce national and global GHG emissions by the 2050's horizon is paramount. NEXT provides annual GHG results that directly respond to the provisions of the transparency framework and its MPGs, and supports the AFOLU P&Ms tracking of an NDC as required by the MPGs. NEXT can also be applied to support policies, programmes and investments in the AFOLU sector, as it provides development agencies and IFIs with a wide set of indicators including the economic mitigation benefits associated with the annual social value of carbon. This indicator allows policy makers and financial institutions interested in accounting for externalities to determine whether the costs and benefits of a proposed policy to curb climate change are justified. Thus, NEXT enables a comprehensive environmental and economic overview of climate actions in achieving a mitigation target, it informs and helps interpret a single NDC achievement as well as collective progress.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

LSS developed the Nationally Determined Contribution Expert Tool and led the manuscript writing under the supervision of MB. All authors contributed equally to the manuscript writing and approved the submitted version.

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