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ENHANCING NDCs: OPPORTUNITIES IN AGRICULTURE

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EXECUTIVE SUMMARY

Highlights

- Climate change directly and indirectly affects food production in many regions, including lost crops and dwindling employment opportunities. These impacts will likely become more severe by 2030 and beyond, placing global food security and the livelihoods of hundreds of millions of people at risk.
- Now is the time to scale up efforts to reshape the agriculture sector to support farmers, avoid the extensification of food production, improve the productivity of farms, build resilience, and reduce emissions. Indeed, the goals of the Paris Agreement cannot be met without transformative changes in the agriculture sector. Incorporating more ambitious, explicit, and directed actions in the agriculture sector in enhanced nationally determined contributions (NDCs) can help make this necessary transition.
- This paper aims to help countries think through the process of enhancing their NDCs by including strengthened actions in the agriculture sector. It underscores the need for tailor-made approaches suited to a country's unique set of circumstances.
- It identifies a range of possible actions for climate change adaptation and mitigation in the agriculture sector, given the right enabling environment in place, and offers examples of how these actions can be included in an enhanced NDC.

CONTENTS

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Context

Climate change is already directly and indirectly impacting food production. Under the current 1°C of warming, climate impacts are already significantly compromising crop yields, and there is evidence of climate-induced human migration associated with climate impacts on agriculture (IPCC 2018). These impacts are likely to become increasingly severe by 2030 and beyond.

Strengthening resilience and reducing emissions in the agriculture sector is necessary in the global climate response. Adaptation to climate change will be a necessary component of efforts to eradicate poverty and hunger. At the same time, mitigation within the agriculture sector is an essential component of any effort to limit global temperature rise and avoid the most severe climate impacts.

NDCs are an important lever to foster productive, resilient, and inclusive farming practices, while keeping the global temperature rise to 1.5°C. Indeed, as this paper discusses, NDCs can help increase support for adaptation, build the resilience of small-scale and vulnerable farmers, reduce emissions in the agriculture sector, bring together climate with other sustainable development objectives, and attract investment and support.

Although more than 90 percent of current NDCs mention agriculture in some way, the coming round of NDC updates in 2020 presents an opportunity to more fully seize the opportunities available in the agriculture sector. This means being more explicit about the actions and investments each country intends to make, what it will take to achieve those changes, and, if applicable, what support is needed.

About This Paper

The purpose of this paper is to promote more ambitious and directed inclusion of agriculture in enhanced NDCs, covering considerations of the enabling environment, as well as actions that can support both adaptation and mitigation imperatives. The paper also provides examples to countries as to how this ambition can best be incorporated in enhanced NDCs, given differing national circumstances.

The paper is a contribution to the Climate and Clean Air Coalition (CCAC) Agriculture Initiative, which is working toward increasing the ambition for agricultural climate action to reduce short-lived climate pollutants (SLCPs), including methane, black carbon, hydrofluorocarbons (HFCs), and tropospheric ozone. Addressing SLCPs in the agriculture sector is particularly relevant given that the sector is one of the largest sources of SLCPs, which also negatively impact air quality and crop yields.

The paper complements resources developed by World Resources Institute, Oxfam, United Nations Development Programme, and other partners that are designed to help national governments develop enhanced NDCs for submission to the United Nations Framework Convention on Climate Change by 2020. These resources include overarching NDC enhancement guidance (see Fransen et al. 2019), as well as sector-specific modules that provide details on enhancing key sectoral components of NDCs.

Foundations for Action: The Enabling Policy Environment

As policymakers look toward including strengthened agriculture actions in an enhanced NDC, it is important they first lay the foundation through enhanced policies, finance, and governance. Doing so will help ensure that enhanced NDCs are tailored to a country's unique set of circumstances and needs, and are aligned with a broader set of food security, equity, and sustainable development imperatives, thus maximizing the chances of successful implementation. This includes the following:

- **Scoping the national context:** Because conditions vary widely across geographies, economies, and societies, any enhanced NDC should avoid a "one-size-fits-all" approach and carefully consider key characteristics of a country's agriculture sector. This includes an examination of national production and consumption trends of crops and livestock, as well as the types and sizes of producers.
- **Involving stakeholders at the outset to strengthen the legitimacy, quality, and durability of the NDC.** Stakeholders include not only relevant government ministries but also farmers, indigenous peoples, and local communities at the national, subnational, and local levels so that diverse perspectives, needs, and priorities are incorporated. Small-scale agriculture producers, especially women and women's organizations, should be explicitly included, which requires targeted and sustained

attention from policymakers. Likewise, it is important to engage stakeholders that will be responsible for the implementation of agricultural climate action to maximize buy-in.

- **Establishing policy coherence.** Countries can consider progress made toward implementing existing goals and policies, and their coherence with other relevant plans, including other climate policies.
- **Strengthening measurement, reporting, and verification (MRV).** Credible MRV in the agriculture sector—encompassing mitigation, adaptation, and support—is foundational for designing an enhanced NDC. MRV provides accessible, understandable, relevant, and timely information and data to inform the design of new climate targets and policies. It deepens understanding about actions to address climate change to discern what works, what does not, and why. MRV can also be a useful communication tool for motivating climate change action, both within government and among external stakeholders.
- **Identifying opportunities for support.** Many countries will require support to fully implement agricultural contributions in their NDCs. This includes access to international climate finance, as well as domestic support such as improved extension services for farmers, including more widespread use of digital services such as early warnings and seasonal forecasts, and redirecting agricultural support to improve agricultural resilience and reduce emissions. The NDC enhancement process offers an opportunity for countries to identify needs and attract support.
- **Ensuring equitable, inclusive governance.** It is important to anticipate whether and how proposed activities benefit or harm lives and livelihoods when advancing agricultural climate action. Careful design of incentive structures and finance flows can help facilitate equitable benefit sharing, while safeguard measures and rights-based approaches can help minimize harms.

Actions to Reduce Emissions and Build Resilience in the Agriculture Sector

A range of actions that have demonstrated technical potential to reduce emissions in the agriculture sector and increase global food production are presented in this paper. If implemented with the right enabling policy environment as described above, they may also lead to improved resilience, food security, and livelihoods for farmers. These actions include improving crop management, livestock management, broader land management, and more sustainable production and consumption measures. The actions presented in this paper are nonexhaustive, but rather illustrative of the range of possibilities in the agriculture sector. We do not argue for full implementation of all actions in every country because some solutions will not be relevant or feasible everywhere or at every farm size. Policymakers will need to decide which actions are relevant for them and whether they merit inclusion in an enhanced NDC.

Agricultural Contributions for Inclusion in an Enhanced NDC

There are many options to include agricultural contributions in an enhanced NDC, which are not mutually exclusive. Depending on national circumstances and priorities, some countries may choose to strengthen the implementation of existing agricultural climate policies and targets; add specific policies and actions to build resilience and enhance adaptation; add specific policies and actions to reduce emissions; incorporate additional agriculture-sector action into an emissions reduction target; and/or include additional information to improve understanding. The paper presents practical examples of the types of agricultural contributions that can be included in an enhanced NDC.

1. INTRODUCTION

Climate change directly and indirectly impacts food production in many regions of the world, including lost crops and dwindling employment opportunities. Under the current 1°C of warming, climate impacts are already compromising crop yields at a significant level, and there is already evidence of climate-induced human migration associated with climate impacts to agriculture (IPCC 2018). These impacts are likely to become increasingly severe by 2030 and beyond, placing global food security and the livelihoods of hundreds of millions at risk. Across the globe, about 2.5 billion people depend on agriculture for their livelihoods (FAO 2013).

Adaptation to climate change, particularly for small-scale producers that comprise the majority of farmers around the world, will be necessary to efforts to eradicate poverty and hunger. Without adaptation, researchers now estimate that climate change could depress growth in global crop yields by 5–30 percent by 2050 (Porter et al. 2014). The 500 million small farms around the world would be most affected (Lowder et al. 2016). Moreover, farmers and other rural people constitute a significant portion of the 100 million people within developing countries that climate change could push below the poverty line by 2030 (Hallegatte et al. 2016).

At the same time, the agriculture sector accounts for more than 13 percent of global emissions (Climate Watch 2019a), rising to nearly a quarter of global emissions when accounting for land-use change (IPCC 2019). Mitigation is therefore an essential component of global efforts to limit global temperature rise to 1.5°C and avoid the most severe climate impacts and end global poverty and hunger.

Indeed, the world cannot meet the Paris Agreement goals without helping farmers adapt to climate impacts while also reducing emissions from major sources of agriculture and land-use change emissions (IPCC 2019). See Annex 1 for details.

Now is the time to scale up efforts to shift the agriculture sector to improve livelihoods, enhance food security, avoid the extensification of production, build resilience, and significantly reduce emissions. Ambitious, explicit, and directed[1] inclusion of agriculture in enhanced nationally determined contributions (NDCs) is important to driving these necessary changes.

Addressing (and not exacerbating) structural inequalities in the agriculture sector will also be critical—for example, by ensuring that actions taken do not disproportionately benefit actors with large capacities, resources, and emissions footprints at the expense of those who need financial support and greater adaptive capacity to realize food security and durable livelihoods (i.e., especially small-scale women farmers, youth, and vulnerable communities). Indeed, it is important to consider what policies and measures can help meet both the adaptation and mitigation goals of the Paris Agreement while protecting and realizing wider benefits for small-scale farmers, who are often marginalized in the agriculture sector, in line with the Paris Agreement's goals of food security and poverty alleviation. Climate change poses a significant challenge to the livelihoods of small-scale food producers. Globally, around 500 million farms are two hectares or smaller, and two-thirds of adults working in poverty make a living in part through agriculture (Bapna et al. 2019). Accordingly, this paper has a strong focus on protecting the livelihoods of small-scale farmers, although the findings and recommendations can be applicable to all farm sizes, producers, and national governments.

Although more than 90 percent of current NDCs mention agriculture in some way (such as needs for support, inclusion in an economywide target, or specific policies and actions that address agriculture mitigation and/or adaptation), the coming round of NDC updates in 2020 presents an opportunity to more fully seize the opportunities available in the agriculture sector to be more explicit about the transformations each country intends to achieve, what it will take to get there equitably, and, as applicable, what support is needed.

The purpose of this paper is to help countries identify ways to enhance their NDCs by incorporating solutions that will make their agriculture sector more sustainable, equitable, and resilient with reduced emissions. It is aimed at national policymakers who are tasked with updating their country's NDC, as well as agriculture policymakers and other stakeholders looking to leverage their NDC to improve agriculture policies and practices and help communities that depend on agriculture for their livelihoods—especially vulnerable populations and women—not only survive but thrive.

The paper unfolds as follows: Section 2 considers why a country might include enhanced agriculture measures in a new or updated NDC. Section 3 examines key aspects and foundational measures of the enabling policy environment likely necessary for advancing agricultural climate action in the context of enhanced NDCs. Section 4 presents an illustrative set of agriculture actions to reduce emissions and/or promote resilience. Section 5 connects the ideas in the first four sections and offers practical examples for reflecting agriculture in an enhanced NDC. Section 6 states conclusions.

The actions presented in this paper are nonexhaustive, but rather illustrative of a range of considerations to enhance the agricultural contribution of a country's NDC. We do not argue for full implementation of all actions in every country because some solutions will not be relevant or feasible everywhere, or at every farm size. Policymakers will need to decide which actions are relevant for them and whether they merit inclusion in an enhanced NDC. Moreover, although the options discussed here are necessary for national governments to consider, they alone will be insufficient to realize the scale of transformation needed in the agriculture sector. While beyond the scope of this paper, changes to trade policies, food transportation and processing, food workers' rights, among other aspects of the food system, need to be assessed and improved concurrently. The paper does not cover ocean-based foods and farming.[2]

This paper is an input document to the Climate and Clean Air Coalition (CCAC)'s Agriculture Initiative, which is working toward increasing the ambition for agricultural climate action to reduce short-lived climate pollutants (SLCPs), including methane, black carbon, hydrofluorocarbons (HFCs), and tropospheric ozone (including through enhanced NDCs). It covers all greenhouse gases (GHGs) and pollutants relevant to agriculture, and highlights the additional development benefits that come with the mitigation of SLCPs, such as improved air quality, which benefits human health and crop yields. The agriculture sector is one of the largest sources of SLCPs.

The paper is complementary to other resources designed to help national governments develop enhanced NDCs for submission to the United Nations Framework Convention on Climate Change (UNFCCC) by 2020. These resources include overarching NDC enhancement guidance (Fransen et al. 2019), as well as sector-specific modules that provide details on enhancing key sectoral components of NDCs. The module on NDC enhancement opportunities for forests and related land-use aspects (Sato et al. 2019) is relevant to the agriculture sector given the close linkages between agriculture, forests, and land use. Another module on strengthening SLCP-reduction commitments in enhanced NDCs (Ross et al. 2018) is also relevant. The CCAC has also published guidance on linking air quality and climate in enhanced NDCs (Malley et al. 2019).

Box 1 | About NDCs and NDC Enhancement

Before the 2015 United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP21) in Paris, Parties submitted "intended" NDCs setting out their country's contribution to addressing climate change. The NDCs were "intended" because the goals and specific terms of the Paris Agreement were not yet agreed on. Now that the Paris Agreement is in force, the NDCs are no longer "intended" but rather constitute the targets, policies, actions, and measures that Parties have agreed to implement domestically.

The term "NDC enhancement" captures the idea of NDC progression inherent in the Paris Agreement, starting with the invitation to communicate new or updated NDCs in 2020 (Fransen et al. 2017). NDCs can be enhanced along various dimensions, including mitigation ambition, implementation, adaptation, and transparent communication. Ideally the NDC enhancement process will bring NDCs more closely into alignment with the goals of the Paris Agreement, maximize the benefits of NDCs for development and resilience, incorporate relevant opportunities to strengthen implementation, and improve transparency.

Terms related to NDC enhancement:

- **New or updated NDC:** From the Conference of Parties decision adopted with the Paris Agreement (1/CP.21), these terms refer to the request in the COP decision to Parties concerning NDCs in 2020. A new NDC is one subsequent to the initial NDC when a Party's initial NDC contains a time frame up to 2025. An updated NDC is one communicated by a Party whose initial NDC contains a time frame up to 2030.
- **Enhanced NDC:** In this paper, a new or updated NDC improves upon the initial NDC with respect to mitigation (ambition and/or implementation), adaptation, and/or communication.

This paper focuses on opportunities to enhance NDCs with a focus on the agriculture sector.

Source: Fransen et al. 2019.

2. AGRICULTURE AND NDCs

This section describes why it is important to address agriculture in NDCs and how it was addressed in the first round of NDCs.

The Case for Addressing Agriculture in NDCs

Multiple benefits arise from addressing agriculture in NDCs: fostering increased support for adaptation, supporting small-scale and vulnerable farmers, reducing emissions from the agriculture sector, bringing together climate with other sustainable development objectives, and attracting investment and support.

Foster increased support for adaptation

Rising temperatures, increasingly variable precipitation, increased frequency of droughts and severe weather events, wildfires, and other aspects of climate change are affecting and will continue to affect the lives and livelihoods of farmers, and how and where food is produced around the world. Actions to respond to increasingly severe impacts can be made more socially inclusive and participatory when planning starts—well before farmers find themselves in crisis. While adaptation in agriculture received significant focus in initial NDCs (FAO 2016a), an enhanced NDC presents an opportunity for national governments to consider and communicate their acknowledgment of the need to plan for more significant changes over the longer term while supporting near-term changes. Significantly enhanced support across the entire agriculture sector will be essential to improve resilience and protect the lives and livelihoods of farmers and their communities.

Support small-scale and vulnerable farms and farmers

Across the globe, about 2.5 billion people, most of them with only one or two hectares of farmland, depend on agriculture for their livelihoods (FAO 2013). Agriculture plays a core role in the livelihoods of many small-scale farmers and their communities; beyond economic support, it also holds deep social importance and cultural heritage, especially to indigenous peoples and pastoralist communities (Fraser 2009). An enhanced NDC presents an opportunity for national governments to increase their focus on the rights and needs of particularly vulnerable small-scale farms and farmers, and engage in inclusive, transparent, and participatory planning and implementation processes.

Reduce emissions from the agriculture sector

Direct GHG emissions from agricultural production comprised 13 percent of total global emissions in 2016 (Climate Watch 2019a), rising to nearly a quarter of global emissions when also accounting for land-use change (IPCC 2019). Emissions from the agriculture sector continue to rise, primarily driven by growing global demand for resource-intensive foods like meat and dairy as incomes rise and the increasing use of synthetic fertilizer, particularly in middle- and higher-income countries (Searchinger et al. 2019). The agriculture sector also contributes to 40 percent of global black carbon emissions, mainly from open-field burning of agriculture waste (CCAC 2019). Indeed, the agriculture sector is one of the largest sources of SLCPs, which have a powerful impact on global temperature and the climate system, and negatively impact food production (see Box 2). Fortunately, as this paper will demonstrate, there are many practical opportunities to realize adaptation and sustainable development cobenefits when reducing emissions in the agriculture sector. Addressing the agriculture sector in an enhanced NDC provides countries with an opportunity to present actions that will significantly reduce emissions, in addition to strengthening adaptation and support.

Bring together climate with other sustainable development goals

Advancing agricultural climate action—and subsequently reflecting this action in an enhanced NDC—can bring together climate with other Sustainable Development Goals (SDGs), such as ending hunger, supporting sustainable livelihoods, and reducing poverty, which help to make addressing climate change more local and resonant for politicians, farmers, and citizens. The discussion could shift from one focused on "what to give up/cut/pay for," to one where the questions are centered on broader social, economic, and environmental considerations such as:

- How can we ensure better lives for farmers?
- How can we enhance food security and end hunger in a changing climate?
- How can we sustainably improve agricultural output and productivity?
- How can we ensure that food systems are sufficiently resilient to climate impacts, even as these impacts intensify?
- What actions can be taken to advance the above objectives simultaneously?

Attract investment and support

Many countries have noted the need for international support to implement their NDCs. Including specific actions and targets for the agriculture sector in enhanced NDCs will send a clear signal to investors and international institutions, making it easier to attract private investment or international support for more sustainable and climate-resilient approaches to the agriculture sector, including specific considerations for small-scale farmers.

Box 2 | **Agriculture and Short-Lived Climate Pollutants**

The agriculture sector is one of the largest sources of short-lived climate pollutants (SLCPs), including methane, black carbon, and the precursors of tropospheric (ground-level) ozone, which is formed in the atmosphere. In agriculture, methane comes primarily from enteric fermentation and rice production; it is also a major precursor to tropospheric ozone. Black carbon is released from incomplete combustion processes such as open agricultural burning.

SLCPs have a powerful impact on global temperature and the climate system, particularly over short time horizons. For example, methane has a significantly higher global warming potential than carbon dioxide (CO_2)—86 times that of CO_2 over 20 years—and black carbon can increase atmospheric warming and the melting rate when deposited on ice and snow. Limiting warming to 1.5°C, with no or limited overshoot, will require deep reductions in emissions of both methane and black carbon—35 percent or more of both by 2050 relative to 2010 levels (IPCC 2018).

SLCPs also negatively impact food production. Tropospheric ozone causes damage to plants through damages to cellular metabolism, which affect leaf-level photosynthesis and carbon assimilation, as well as whole-canopy water and nutrient acquisition and ultimately crop growth and yield (Emberson et al. 2018). High ozone concentrations could lead to an increase in crop damage of up to 20 percent in agricultural regions in 2050 (IPCC 2019). Black carbon also affects leaf-level photosynthesis and carbon assimilation. Without ambitious actions to tackle SLCPs, it is estimated that 52 million metric tons of staple crops could be lost each year (WMO and UN Environment 2011). Indeed, the health and agriculture gains from reducing SLCP emissions are among the many reasons that instituting mitigation measures for these pollutants can be closely aligned with achieving the 2030 Sustainable Development Goals (Haines et al. 2017) and efforts to reduce poverty (Hottle and Damassa 2018).

Agriculture in the First NDCs

In their first NDCs, most countries identified agriculture as a key sector for action, both in terms of mitigation and adaptation—often referring to synergies and cobenefits between the two. This section presents a brief overview of agriculture in first NDCs. For a full examination, refer to the FAO (2016a, 2016b).

Adaptation

The NDCs of 131 countries (out of 189 total) included agricultural adaptation policies and measures (Figure 1), the vast majority of which focus on crops and livestock, including water management and irrigation. A significant number also prioritize disaster risk management (FAO 2016a).

Mitigation

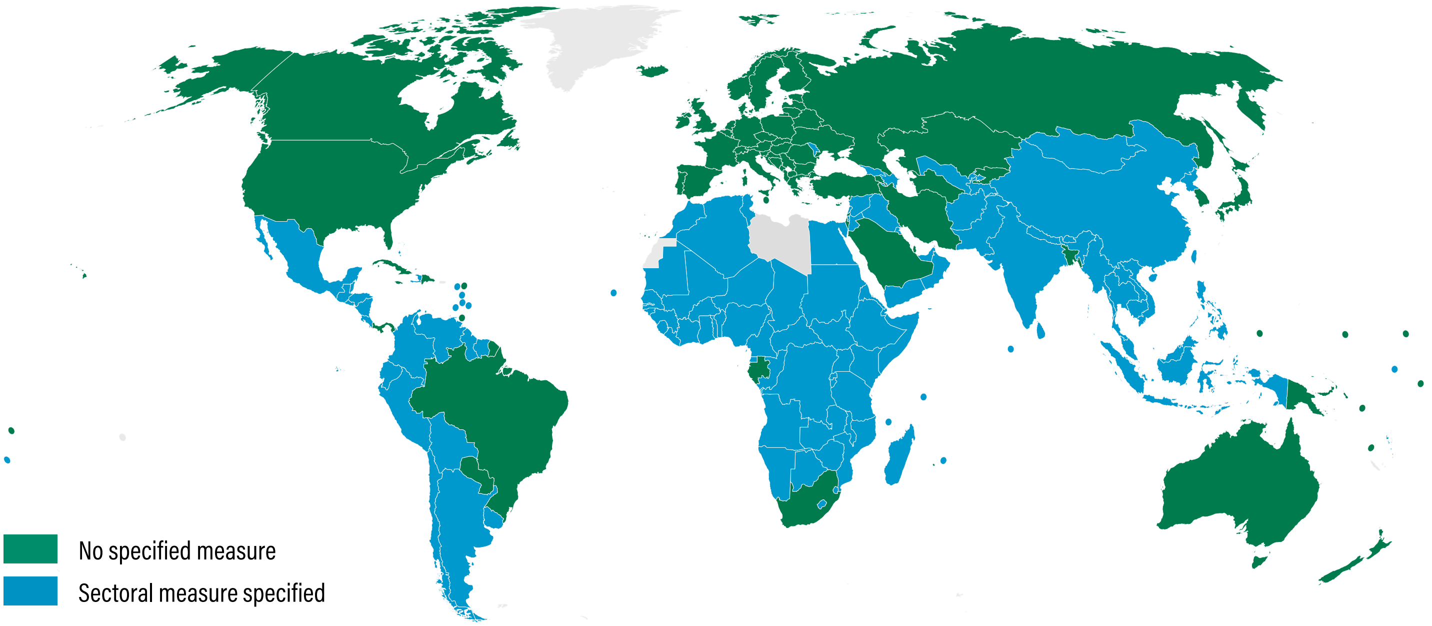
In the first round of NDCs, 128 countries included agriculture in an economywide GHG emissions target in their NDC. And 59 countries included agricultural mitigation policies and measures typically focused on cropland management, livestock management, and grazing land management (Figure 2) (FAO 2016a).

Looking ahead

Although many countries include the agriculture sector in their NDCs, there are some gaps:

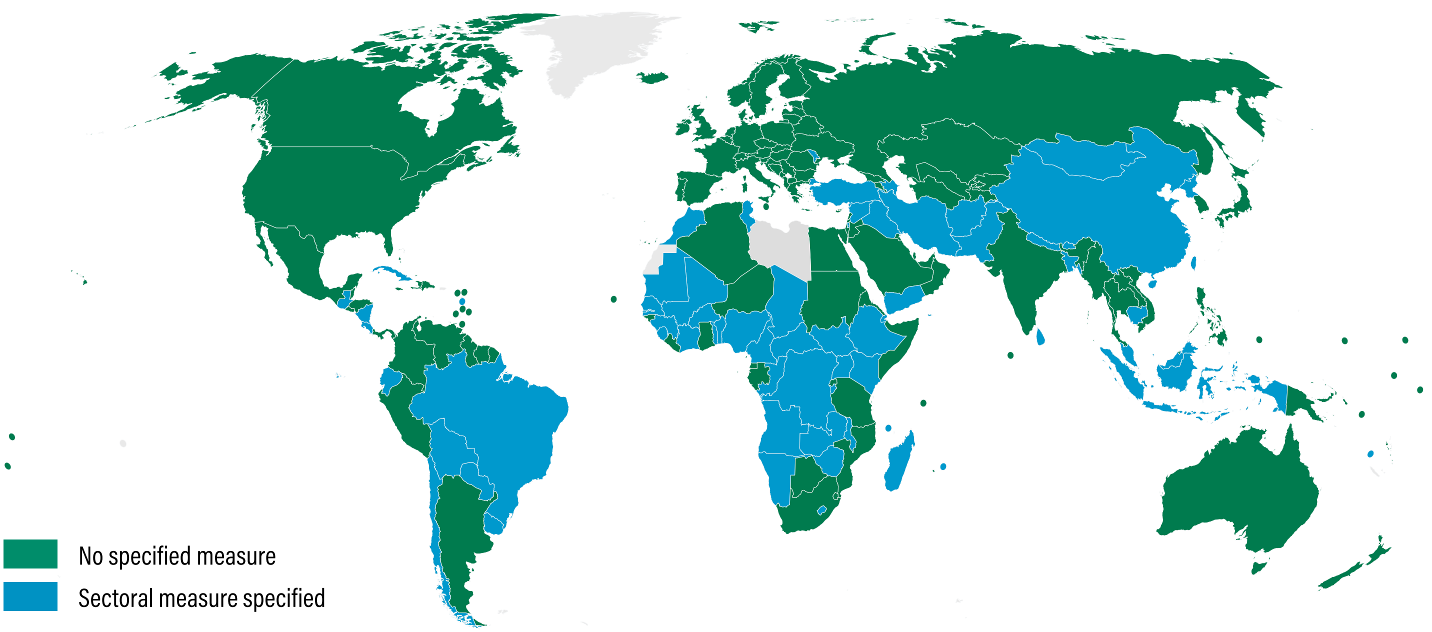
- Mitigation actions in the agriculture sector are generally addressed "on the farm." There is little focus on reducing emissions across the food supply chain, despite it being a significant source of global emissions. For example, no country references the imperative to shift to healthier and more sustainable diets; very few countries include policies or actions to address food loss and waste (Climate Watch 2019b).
- Countries rarely include quantified sector-specific targets for agriculture (FAO 2016a), which can help to provide the necessary specificity to drive targeted action.
- Explicit information regarding financial support to implement activities in the agriculture sector (and particularly resources targeted for the benefit of small-scale women farmers and their communities) is generally lacking.
- Potential synergies between agricultural adaptation and mitigation are not always explicitly described. For example, countries often refer to activities such as

Figure 1 | **Countries Proposing Specific Agricultural Adaptation Policies and Measures in Their First NDCs**



Source: Climate Watch 2019b.

Figure 2 | **Countries Proposing Specific Agricultural Mitigation Policies and Measures in Their First NDCs**



Source: Climate Watch 2019b.

cropland and nutrient management, land restoration, forest management (including mangroves), and protection and preservation of ecosystems that offer opportunities to achieve simultaneous climate change mitigation and adaptation benefits, but without explicitly acknowledging these synergies in their NDCs (FAO 2016b).

- NDCs generally lack detail and specificity regarding how their targets will be achieved.
- NDCs generally lack detail on the policy environment necessary to advance agricultural climate action (see Section 3).

The coming round of NDC updates in 2020 presents an opportunity to more fully seize the opportunities available in the agriculture sector. As explained in the following sections, this means being more explicit about the improvements each country intends to achieve, what it will take to get there, and, for developing countries, which are home to the majority of the world's small-scale farmers, what support is needed.

3. FOUNDATIONS FOR ACTION: THE ENABLING POLICY ENVIRONMENT

As national governments develop enhanced NDCs, they have an opportunity to consider, incorporate, and/or reform their policy environment to foster productive, resilient, and inclusive farming practices. Consideration of the issue areas presented in this section, among others, can help ensure that agricultural climate action is tailored to a country's unique set of circumstances and needs and aligned with a broader set of food security, equity, and sustainable development imperatives, thus maximizing the chances of successful implementation. Indeed, many of these issue areas may even lead to emissions reductions and/or increased resilience in their own right and can be included in an enhanced NDC to better support implementation (read more in Section 5). This includes scoping the national context; aligning plans; involving stakeholders; intragovernmental coordination; strengthening measurement, reporting, and verification; modeling and analysis; identifying opportunities for support; and ensuring equitable, inclusive governance. This section draws in part from Fransen et al. (2019) and expands on certain concepts that are particularly relevant to the agriculture sector.

Scoping the National Context

Because conditions vary widely across geographies, economies, and societies, any enhanced NDC should avoid a "one-size-fits-all" approach and carefully consider key characteristics of a country's agriculture sector. For example, foundational information could include the following:

- *Production and consumption trends of crops, including commodity crops, relevant to an economy, as well as associated contributions to, and anticipated impacts from, climate change.* For example, while many crops are grown for sustenance and local food security, a handful of cash crops—for example, soy, beef, and palm oil—dominate trade across borders, and are associated with a significant amount of GHG emissions due to land conversion (Searchinger et al. 2019; Pendrill et al. 2019; Meyfroidt et al. 2014).[3] Additionally, while climate impacts on crop yields vary by region, they are expected to be generally detrimental in most regions beyond 2030 (particularly in the tropics), as yields of wheat, corn, and rice could be reduced by 10–25 percent for each degree of global mean surface temperature increase (Deutsch et al. 2018).[4]
- *Production and consumption trends of livestock products and their environmental, economic, and cultural relevance within the agriculture sector.* Global demand for milk and meat from grazing ruminants (i.e., cattle, sheep, and goats) is currently projected to grow even more than demand for crops in the coming decades (Searchinger et al. 2019). However, there are important differences in livestock management around the world. For example, wealthier countries tend to have more large, concentrated animal feeding operations with higher emissions per hectare, but also relatively efficient performance in terms of GHG emissions per unit of meat and milk production (Herrero et al. 2013; Vermeulen and Wollenberg 2017). Meanwhile, an estimated 1 billion people depend on livestock for food and family income, and for an estimated 100 million people in arid areas, grazing livestock is the only possible source of livelihood (FAO 2013).
- *Trends and potential changes in the structure of agriculture, including the role of large multinational businesses and small-scale producers.* In recent decades, corporate retailers and traders have increasingly consolidated ownership of value chain

segments often to the detriment of small-scale farmers (Willoughby and Gore 2018). Yet across the globe, 2.5 billion people, encompassing farmers, pastoralists, forest dwellers, and fishers, among others, depend on agriculture for their livelihoods, typically with only one to two hectares of farmland. Most of this farming labor force is currently in Asia and sub-Saharan Africa, where agriculture accounts for more than 50 percent of employment in most countries (World Bank 2019). However, these regions are industrializing and urbanizing, with potential implications for the structure of food production and consumption, sometimes to the benefit of urban consumers through lower food prices, and increased quantity and quality (Reardon et al. 2014).

- *Land-use changes and the legal context*. Scoping includes determining who lives on, depends on, owns, and manages agricultural land across the country, and how much of this land is managed by traditional or indigenous communities, small-scale versus large-scale farmers, or the state, as well as how much land is subject to tenure disputes. National agriculture actions generally involve land-use decisions by a range of actors across different ecosystems, such as watersheds, forests, or agricultural land. Plans for enhanced actions are easier to develop and implement when land tenure is generally undisputed, and the rate of land-use change (for example, conversion of forests to agriculture) is relatively low.

The scoping process involves getting a full understanding of the national agriculture sector and conceptualizing a policymaker's approach to an NDC; that is, how the current context will inform the type of future action.

Establishing Policy Coherence

In the process of designing enhanced commitments for the agriculture sector, it is useful to consider progress made toward implementing existing targets and plans. New commitments could be informed by experiences, challenges, and lessons learned. It is also useful to review any changes in national circumstances, political priorities, development priorities, and efforts to achieve SDGs (including progress made toward relevant sectoral SDG targets). Countries could also review existing or planned national adaptation plans (NAPs), national adaptation programmes of action (NAPAs), nationally appropriate mitigation actions (NAMAs), options to combat desertification, and biodiversity targets, which can help identify new opportunities and synergies to pursue agricultural climate change strategies in tandem with other national priorities. It is also important to identify links between national and subnational climate and agricultural policies, including the "mid-century long-term low-GHG-emissions development strategies" that many countries are preparing in response to an invitation under the Paris Agreement.

Involving Stakeholders: Establishing a Multistakeholder Platform for Planning and Implementation

Engaging stakeholders can greatly strengthen the legitimacy, quality, and durability of the NDC (Fransen et al. 2019). Engagement includes participatory planning with self-selected representatives of farmers, cooperatives, indigenous peoples, and local communities. Enhanced stakeholder planning across the national, subnational, and local levels enables governments to develop NDCs that better incorporate diverse perspectives, needs, and priorities. Because so many farmers are already facing climate impacts, this broad range of stakeholders has both information needs and knowledge to share regarding effective adaptation and mitigation measures. Small-scale agriculture producers, especially women and women's organizations, merit inclusion and targeted attention from policymakers. Likewise, it is important that stakeholders who will be responsible for the implementation of actions included in the NDC are engaged at the outset to ensure buy-in and maximize the likelihood of implementation. Depending on in-country linkages between agriculture and forests, countries may wish to build on existing REDD+ multistakeholder platforms.

Intragovernmental Coordination

The development of enhanced NDCs offers an opportunity to learn from experience by engaging all relevant ministries (e.g., agriculture, water, transportation, finance, trade, energy, and others). In many cases, the initial NDCs were created in isolation by climate change departments within ministries of environment. Strengthened engagement can support political buy-in for the enhanced NDCs and ensure that the NDCs are more effectively implemented. In addition, aligning enhanced NDCs with other climate, agriculture, and economic development plans can increase support for them beyond what stand-alone plans could achieve.

Climate action plans are most effective when they are closely aligned (if not combined) with the goals and objectives articulated in economic and development plans, such as SDGs, national adaptation plans, and national climate action plans. If not integrated into such plans, NDCs and the institutions that create them may compete with other initiatives led by different ministries for resources and influence, making implementation all the more challenging. Strong collaboration and coordination across government, as well as from the national to the local level, while NDCs are being drafted can increase the effectiveness and ease implementation. Resource and capacity restraints for many developing countries underline the need for better alignment and identification of synergies to reduce duplication and costs.

Strengthening Measurement, Reporting, and Verification

Credible measurement, reporting, and verification (MRV) in the agriculture sector (encompassing mitigation, adaptation, and support) is foundational for designing an enhanced NDC. MRV provides accessible, understandable, relevant, and timely information and data, thus helping inform the design of new climate targets and policies. MRV deepens understanding about actions to address climate change to discern what works, what does not, and why. MRV can also be a useful communication tool for motivating climate change action, both with other government departments (outside environment departments) and external stakeholders.

MRV is still developing in many sectors, but the agriculture sector faces deeper challenges. Countries in all regions of the world consistently mention problems encountered with collecting activity data for agriculture, which limits their ability to conduct robust inventory work (Salvatore 2018). Many developing countries also highlight a lack of data to estimate emissions factors for agricultural mitigation activities. For example, due to the ecological, social, and economic complexity of many agricultural landscapes, it is often difficult to determine the right baseline and the GHG mitigation over time (Salvatore 2018). Indeed, in their first NDCs, some countries requested training on how to calculate GHG emissions and removals from the agriculture sector, while others highlighted the need for support to develop better MRV practices (FAO 2016b). Many developing countries also prefer to prioritize adaptation actions that may not be possible to numerically quantify.

Although improving MRV systems will take time and significant capacity, policymakers should not allow this to hinder their will and effort toward undertaking strengthened agricultural climate action. Indeed, in many cases, high-level inventory data is sufficient to identify major sources of emissions in the agriculture sector and develop actions to target those emissions. In many other cases, countries can enhance agriculture actions with nonquantifiable contributions (see Section 5).

Modeling and Analysis

New agricultural mitigation and adaptation targets and actions should ideally be informed by robust modeling and analysis. Through these exercises, countries can identify cost-effective and cost-beneficial actions that have significant mitigation potential and/or reduce climate impacts and vulnerabilities. Several tools can support these types of analyses. For example, the Food and Agriculture Organization of the United Nations' (FAO's) Global Livestock Environmental Assessment Model can help to identify environmental impacts of livestock in order to develop more sustainable approaches (covering both mitigation and adaptation). A qualitative approach overlaid on the modeling results can help identify the impacts of these actions on farmers and livelihoods. If modeling is conducted, the high-level results and assumptions can be included in the enhanced NDC to facilitate clarity, transparency, and understanding of how the mitigation goals and actions in the agriculture sector have been developed.

Identifying Opportunities for Support

Support is needed from both international and domestic sources.

International support

According to the FAO's 2016 analysis of national contributions in agriculture, all least developed countries and the vast majority of other countries require international support to implement their contributions (FAO 2016a). International support may be multilateral or bilateral. The Green Climate Fund, the Adaptation Fund, the Adaptation for Smallholder Agriculture Program (at International Fund for Agricultural Development [IFAD]), Asia Pacific Climate Finance Fund (at the Asian Development Bank [ADB]), and the World Bank's Biocarbon Fund are all examples of multilateral public funds for climate finance related to agriculture.

Multilateral public financial institutions as well as many bilateral agencies typically prioritize their support based on a blend of country and contributor priorities as well as policies and procedures to avoid (or at least reduce) social, environmental, and economic harms—which can be particularly acute in land sectors. Although this paper does not identify all policies relevant to transforming the agriculture sector, many of its recommendations reflect key elements across international financial institutions' policies as related to climate change and agriculture. Private finance and market-based (or even nonmarket-based) mechanisms have significant potential both for heightened risks and new opportunities for farmers. While such considerations merit far more depth than this paper can address, as a general principle, countries may find fewer barriers to accessing international support if they have already developed safeguard systems such as REDD+ safeguards (see safeguard section below).

Establishing transition funds is an emerging way that countries can assist small-scale producers to better manage climate risks that countries could consider including in their NDCs. Such funding streams are distinct from conventional adaptation finance in that they are reserved for situations in which farmers face such significant climate-related stresses that they must transition to alternative production systems, such as alternative crops or livestock varieties, or leave farming altogether. Governments could provide direct support to these farmers, earmark funds specifically for planning and implementing such transitions, or provide assistance in establishing new marketing networks for alternative products (Bapna et al. 2019).

Domestic support

Domestic support can include improved farm extension services, subsidies and market reforms, and financial incentives to equitably share benefits and risks.

IMPROVED EXTENSION SERVICES FOR FARMERS

Agricultural extension (the provision of information to farmers) plays a crucial role in boosting agricultural productivity, increasing food security, improving rural livelihoods, and promoting agriculture that supports pro-poor economic growth (IFPRI 2019). Extension—particularly when it is farmer-driven and gender-responsive—can provide a critical support service for rural producers meeting the new challenges confronting agriculture, including adapting to climate change. Greater use of digital communication technologies to provide critical weather information and seasonal forecasts can help farmers adapt to shifting seasonal patterns by better timing planting and harvesting. More support for farmer-to-farmer education and enhanced data and analytics to improve disease surveillance and provide early warning of pest outbreaks are also critical (Bapna et al. 2019).

The FAO proposes four main elements of agricultural extension: knowledge and skills, technical advice and information, farmer organizations, and motivation and self-confidence (FAO 2019). When agricultural extension is applied in the context of climate change, it offers great potential to enable farmers to make informed decisions, better manage risk, take advantage of favorable climate conditions, and adapt to change (CCAFS 2019). Improved extension is also important as farmers seek to manage risk by diversifying their incomes (Bapna et al. 2019). This may include learning to produce new varieties of crops and livestock that are more resilient but require different cultivation techniques, processing, or marketing channels (Carter et al. 2018).

SUBSIDIES AND MARKET REFORMS

Government policies already provide major financial support to agriculture. According to estimates by the Organisation for Economic Co-operation and Development (OECD), the 51 top countries in total agricultural production (excluding countries in South Asia, which the OECD data do not address) provided nearly $600 billion in farm support in 2015 (Searchinger et al. 2019). Redirecting agricultural support provides a major opportunity for improving agricultural resilience and reducing emissions from the sector. This could include redirecting subsidies that currently encourage farmers to produce foods in locations or ways that increase environmental harm and undermine long-term sustainable, climate-mitigating, climate-resilient production (Bapna et al. 2019). This may be politically challenging because even while redirecting these subsidies might benefit the sector as a whole, individual farmers who lose direct financial subsidies or market protections are likely to oppose such reforms. While a full examination of market reforms and agricultural subsidies is beyond the scope of this paper, Searchinger et al. (2019) recommends increasing attention to farm programs by individuals and public officials who care most about climate change, biodiversity, and global poverty. These Parties have an important stake in structuring farm support programs, though the connection is often not always sufficiently recognized (Searchinger et al. 2019).

EQUITABLY SHARING BENEFITS AND RISKS

Financial incentives may include direct access to loans or other financial products, risk-sharing mechanisms, output and results-based payments, and private investment measures (Streck 2012). Diverse interests, approaches, and capacities in a country's agriculture sector suggest that multistakeholder platforms can be particularly useful in helping structure finance and other support to help facilitate equitable and inclusive outcomes. For example, direct participation in decision-making can help small-scale farmers identify and overcome barriers to scaling up climate action in agriculture (Ruben et al. 2019). Extension services, technological support, and direct financial incentives can help to overcome these barriers, especially when combined with sustained technical support and capacity building. Similarly, it is important to consider various scales and production capacities when implementing measures to help reduce risk: many small-scale farmers lack the assets to fully participate in conventional insurance schemes, suggesting that social safety nets and integrated microfinance approaches may be valuable additions to national adaptation support measures if benefits outweigh the costs. Weather-based crop insurance, which compensates farmers based on indices of the severity of harmful events and the damage they cause, rather than requiring farmers to submit claims and wait for payouts, is an emerging option that may prove to be a more effective way of stabilizing farm incomes (Bapna et al. 2019).

Enabling Equitable, Inclusive Governance

NDCs offer an opportunity for countries to highlight country dedication to equality and inclusivity in the agriculture sector. Like other contributions affecting land, foundational agricultural climate measures need to anticipate whether and how proposed activities benefit or harm people—especially small-scale farmers and their communities—and specifically women, youth, indigenous peoples, and the vulnerable. Careful design of incentive structures and finance flows, among other components of a national governance enabling environment, can help facilitate equitable benefit sharing, whereas safeguard measures and rights-based approaches can help minimize harm.

Three key issues that can increase opportunities and reduce risks and vulnerabilities of agriculture communities include gender equality, secure land tenure, and upholding social safeguards and rights of small-scale farmers.

Gender equality

Women farmers play a central role in food production and food security. On average, women farmers make up 43 percent of the small-scale and family farm labor force, and an even higher percentage in many developing countries (FAO 2016c). In addition, up to 79 percent of these women depend on agriculture as their primary livelihood (CFS 2016). Yet in many communities, patriarchal norms and historic and cultural factors dictate gender roles and areas of work. As a result, women farmers, on average, hold fewer land and resource rights (UN Women 2019) and have less access to important information, decision-making, income opportunities, and political voice than men. In these communities, women also typically have fewer financial and physical assets, making it more difficult to rebound after a significant storm or drought, and may lack mobility and opportunity to engage in public and private decision-making. In the aggregate, with lower education levels and fewer opportunities for training and less access to extension services compared with men, women remain disadvantaged in the agriculture sector.

The flip side of these significant challenges is that there are ample opportunities for climate-friendly agricultural interventions that can meaningfully improve economic, environmental, and health conditions for women. A recent estimate, for example, projected that if women interested in increasing yields received proper support, including access to extension services, finance, and markets, they could increase agricultural yields by 20–30 percent and decrease global undernourishment by up to 17 percent (FAO 2011a).

To harness the potential for women in agriculture, coordinated effort and investments can help close the gaps and break down the barriers that women face, while simultaneously offering significant social, environmental, and economic benefits and pathways to achieving key development outcomes including improved nutrition and health. Gender-responsive measures include identifying the differential impacts of proposed activities on male and female farmers at both small and large scales; avoiding exacerbating inequalities based on existing tenure and inheritance rules and cooperative rights (OHCHR and UN Women 2013); clarifying how gender dimensions impact financial incentives; and strengthening women's tenure and inheritance rights (Willoughby and Gore 2018).

National governments can support women small-scale farmers by allocating resources directly to them, rather than through a "trickle-down" approach via traditional agricultural spending and climate adaptation programming. Gender-specific budget lines within national planning and tracking of spending disaggregated by gender can help countries to improve their climate change and agriculture planning, implementation, and success. For example, Oxfam's analysis of government and donor investments in Ethiopia, Ghana, Pakistan, the Philippines, and several other countries found that supporting women farmers' participation in local budget decision-making and aligning funding to achieve development outcomes such as poverty alleviation are key to long-term success. At the same time, lack of gender-disaggregated climate data inhibited the ability to monitor gender-related impacts associated with climate-specific spending (Pearl-Martinez 2017).

Land tenure

Farmers are less likely to invest in improvements to their land if they are unsure that they will have secure rights to the benefits of such improvements. Nearly two-thirds of the world's agricultural land is managed by 1 percent of the landowners (FAO 2014). The average size of corporate farms exceeds 50 hectares, a figure significantly affected by consolidation trends in wealthier countries over the past several decades (Lowder et al. 2016; Willoughby and Gore 2018). Both the average farm size and the share of farmland controlled by larger farms are higher in countries with larger average incomes (Lowder et al. 2014). Commodities, in particular, have been associated with a pattern of "land grabs," where longstanding rights holders may become dispossessed by wealthier or corporate interests who convert the land to intense agricultural production for commodities (Borras Jr et al. 2011). As such, it may be important to consider what policies and measures can help to overcome issues around land tenure and protect small-scale farmers. Some of these policies involve targeting support for small-scale farmers and avoiding actions leading to relocation without consent and compensation. Additional agrarian reforms could help to break up large land holdings for redistribution or cap consolidation of land by large-scale actors. National frameworks that align with international obligations, cultural context, and rights-based approaches—especially for established communities with customary rights whose members' livelihoods depend on farming—can go a long way in reducing conflicts while increasing the likelihood of enduring outcomes for sustainable development (RRI 2017).

Social safeguards and rights for small-scale farmers and their communities

The vast majority of the world's farmers work small farms, yet they hold a disproportionately small market share in global value chains across commodities and geographies.[5] Unequal market power (ranging from inputs like limited access to financial services to outputs like a limited choice of buyers), challenge small-scale producers in both domestic and (even more so in) global value chains (Willoughby and Gore 2018). Supporting small-scale farmers means not just investing in mitigation and adaptation efforts but addressing systemic risks such as insecure land tenure and value chain structures. To reduce risks and increase the likelihood that actions yield more benefits than harms, the UNFCCC, the UN General Assembly, international organizations like the United Nations Development Programme (UNDP), and finance institutions like the Green Climate Fund and multilateral development banks have adopted various policies and procedures aimed at protecting the rights and interests of indigenous peoples, local communities, women, and others who identify as small-scale farmers. In addition to institution-specific safeguard policies and grievance mechanisms, international human rights obligations, and instruments such as the UN Declarations on Indigenous Peoples and the Rights of Peasants provide important frameworks for implementing national actions. Countries with REDD+ activities could build from those established safeguard systems to help streamline safeguard implementation.

4. ACTIONS TO REDUCE EMISSIONS AND BUILD RESILIENCE IN THE AGRICULTURE SECTOR

This section presents a selection of actions to reduce emissions in the agriculture sector, which, when implemented with the right enabling policy environment (see Section 3), could serve to also build resilience, enhance adaptation, and improve outcomes for farmers. If the actions below exclude the foundational measures identified in Section 3, there are risks of adverse impacts (e.g., social, environmental, and inequality).

Because NDCs typically contain separate mitigation and adaptation contributions, icons are included next to each action in the section to indicate whether the action can deliver mitigation and adaptation cobenefits, or just mitigation benefits.

The actions below are largely summarized from the *World Resources Report: Creating a Sustainable Food Future* (Searchinger et al. 2019).[6] The *World Resources Report* is global in focus and details technical opportunities and policies for cost-effective scenarios to meet food, land-use, and GHG emissions goals in 2050.

This paper focuses on the agriculture sector and land-based agricultural production practices, although broader food system issues such as reducing food loss and waste and shifting to healthier and more sustainable diets are also examined. Adaptation benefits are included for relevant actions, which are derived primarily from World Resources Institute's work on transformative adaptation,[7] as well as *Adapt Now: A Global Call for Leadership on Climate Resilience,* the flagship report of the Global Commission on Adaptation (Bapna et al. 2019). Recognizing that adaptation measures in agriculture are a priority for many countries in their development of enhanced NDCs, but are not the primary framing of this section, we invite discussions regarding how to strengthen our treatment of adaptation in NDCs, alongside the findings of the recently released *Adapt Now* report, to continue identifying critical, targeted adaptation actions for NDC enhancement.

The actions presented here are nonexhaustive, but rather illustrative of the possibilities in the agriculture sector. We do not argue for full implementation of all actions in every country, as some actions will not be relevant or feasible in different locations. We do not distinguish which actions are most applicable to the type of agricultural producer or farm size. Policymakers will need to consult with stakeholders and decide which actions are relevant for their countries and whether they merit inclusion in an enhanced NDC.

Finally, some agricultural producers may already have sufficient resources and be motivated to implement the actions to achieve economic and productivity gains. Large-scale or industrial actors may have greater resources and capacities to lead on mitigation and adaptation efforts. In other cases, farmers will require support. Special attention should be paid to the poorest and most vulnerable farmers to ensure that actions do not exacerbate inequality or hunger and do foster resilience. Indeed, supporting these farmers sometimes means not just investing in mitigation and adaptation projects but also addressing systemic barriers that enable farmers to develop more sustainable agriculture practices (see Section 3).

Increase Productivity

Mitigation Adaptation

To address growing demands for food production in a climate-constrained environment, sustainable intensification is needed to increase yields and enhance food security. Indeed, the world's farmers can achieve greater crop and livestock yields with improved management (Bapna et al. 2019). Specifically, there are promising options to increase pasture and livestock productivity, some of which may be available to small-scale farmers and pastoralists, if their rights are recognized and interventions are targeted at supporting them. For example, improved productivity often leads to higher incomes, which can provide rural people a better buffer against climate shocks and improve their resilience—which can complement government-supported adaptation measures.

Increased attention to and greater funding for demand-driven research and development is also an essential component of improving the productivity of crops and livestock as the climate changes. While this will often require support from farmers and their communities, development agencies, and the private sector, countries can signal that it is a priority for them by including it in their NDC. In addition, investing in improved digital technology, better weather information, and systems to provide early warnings of pest and disease outbreaks can be helpful in curbing productivity losses and improve resilience (Bapna et al. 2019).

Pasture

On wetter pastures, improved fertilization and rotational grazing can increase productivity. Improving feeding practices during dry seasons and during the "finishing" stage of production can also boost meat and milk output per hectare. In Africa and Asia, "cut and carry" systems—in which farmers cut fresh grasses daily and bring them to their animals—are common. In such systems, growing improved forage grasses and shrubs with high-protein leaves can increase productivity. Intensive (higher-yielding) silvopastoral systems in Colombia integrate shrubs, trees (see "Agroforestry" later in this section), and grasses, and generate several times the milk or meat per hectare versus extensive (lower-yielding) systems, while also being more resistant to drought (Murgueitio et al. 2011).

Improved fodder species can deliver economic and ecological benefits while buffering against increasingly frequent and severe climatic extremes. For example, diversified and improved fodder sources can better support ecosystem services; for example, the soil's ability to retain water, which buffers against droughts (Dinesh et al. 2017). Fodder species rich in micronutrients can help livestock to maintain their nutrient balance and avoid the effects of heat stress, which can cause animals to eat less and lose minerals through sweating (Renaudeau et al. 2012).

Livestock

Along with improving feed quality (see above), better animal health care and breeding can also support higher ruminant productivity, and hence the livelihoods and resilience of livestock producers. Breeding programs have focused on increasing production of meat or milk per animal in recent decades, and these advances have also led to increases in feed efficiency. Ruminant systems have large improvement potential, especially in the tropics. Across beef production systems, current GHG emissions (mainly methane) per gram of protein produced can vary by a factor of 30 across the world due to differences in feed quality, while land use per gram of protein can vary by a factor of 100 (Herrero et al. 2013). Improved livestock productivity will decrease pressure on land expansion for animal feed and fodder, and can benefit smallholders by reducing pressure on land and increasing the quality (and resulting price) of meat. Livestock also accounts for a large amount of water usage (Mekonnen and Hoekstra 2012), which, if reduced through more efficient use, could free up limited water supplies for other uses.

Improving livestock breeding to incorporate more climate-resilient traits can also be a critical element in agricultural adaptation but requires new technology, cultural safeguards, and expanded infrastructure. Crossbreeding of genetically specialized breeds with those that are locally adapted to climate conditions can increase productivity but often at the risk of replacing environmentally adapted traits. To address the impacts of climate change, local breeds can be bred to improve productivity while considering long-term climate conditions of specific environments (Salman et al. 2019).

The approximately 268 million pastoralists (FAO estimate) experiencing high rates of food insecurity, and for whom intensifying climate change impacts will further stress already precarious ecosystems, could be better supported to adapt to climate change through measures such as protecting their rights to pasture, providing assistance with adjusting destocking and restocking rates in response to climatic variability, and with finding additional or alternative sources of income (Bapna et al. 2019). Further, governments should be careful to develop livestock mitigation measures that do not impose additional burdens on pastoralists. Participatory planning and implementation measures as well as appropriate support and incentives help reduce risks and increase benefits to pastoralists and others whose existence and culture depend on livestock for subsistence and food security.

Crop breeding

Improved crop breeding is generally credited for half of all historical yield gains, although it has sometimes necessitated the use of additional inputs such as synthetic fertilizers (Fischer et al. 2014). Breeding can increase the potential yield of crops under ideal conditions and help farmers achieve better yields by better coping with environmental constraints, including a changing climate.

Tailoring breeding to specifically overcome climate challenges (e.g., high temperatures, rainfall variability) could improve crop resilience by reducing losses in climatically challenging years, enabling farmers to increase or at least stabilize their yields. Thornton et al. (2007) estimate that changing crop varieties could be a suitable climate-friendly option for more than 60 million people in sub-Saharan Africa. Consistent funding streams for farmer-driven, participatory research to improve the productivity of less-researched orphan crops such as sorghum, cassava, and pulses are particularly important to improving food security and building resilience in developing countries (Bapna et al. 2019).

Speeding crop cycles could also enable improvements to better keep up with intensifying climate impacts and respond more quickly to emerging, localized challenges such as changed prevalence of disease and pest problems, or increased variability in temperatures and rainfall at specific times of the production cycle.

It is important to note that tailored breeding has become contested, for example, for reasons of social justice, food sovereignty, ownership of genetic resources, and farmers' rights on seed saving (seed sovereignty), and package deals of genetic modification technology, among other issues (Lammerts van Bueren et al. 2018). Improved crop breeding also requires upfront investment (e.g., for seeds, fertilizer, and pesticides), agronomic knowledge, and experience in use of these agricultural inputs (Thornton and Herrero 2014), which may limit small-scale farmers' access to these improved methods. Accordingly, it is essential that seed-based and other breeding solutions are designed in tandem with farmers and their communities and that improved seeds are available to the poor and meet local needs in terms of markets, taste preferences, and labor demands (Ashley et al. forthcoming).

Strong intellectual property protections can help local people benefit from commercialization of traditional or "orphan" crops. Capacity building and investments at the community level, as well as at national and global seed breeding entities, can improve the rate at which new varieties can be tailored to local conditions (Ashley et al. forthcoming). This is important because highly localized and rapidly evolving climate change impacts, such as shifts in wind speed or the timing and intensity of precipitation, as well as outbreaks of pests and diseases, are combining with location-specific differences in soil types, slope, and other factors to make more generic varieties of new seeds less productive. Depending on the context, it can also be important to more rapidly develop improved crop varieties with farmers, reduce barriers to the sale of improved seeds, and increase market access (Bapna et al. 2019). Improving the distribution of improved seed varieties and protecting crop genetic diversity are other crucial aspects of improving crop breeding (Bapna et al. 2019).

Improve Soil and Water Management

Mitigation Adaptation

According to FAO, one-quarter of the world's cropland has degraded soils (FAO 2011b). Degradation is of particular concern in drylands, which cover about 43 percent of Africa and where low soil fertility—which leads to low crop yields—threatens food security (FAO 2011b). Low levels of organic matter also make soils less able to retain water and reduce crop response to fertilizers. In these areas, a combination of soil and water management techniques—including agroforestry, water harvesting, microdosing crops with small quantities of fertilizer, no-burn agricultural methods, and other agroecological approaches not discussed in detail here—provide additional opportunities to boost crop yields (FAO 2018).

Agroforestry

Agroforestry, which integrates trees and shrubs on farms, can be an important way to build resilience while boosting yields. It offers the opportunity to improve the economic and ecological diversification of farming systems through products derived from trees (e.g., fruits, nuts, firewood), which can also improve household nutrition, food security, and incomes. Trees can also shade crops and livestock, and their roots can hold water in the soil and prevent erosion. Agroforestry can also enable sustainable intensification through positive effects on soil fertility, soil health, water-use efficiency, and microclimatic effects (Dinesh et al. 2017).

Trees can also act as buffers against climate and economic shocks. In some situations, integrating trees can reduce ambient temperature by about 2°C, limiting the impacts of hot spells on crops and allowing crops like coffee to continue growing in locations with increasing temperatures. The use of leguminous trees such as acacia to fix nitrogen in the soil can improve yields with fewer negative effects than using inorganic mineral fertilizers. Shading has positive effects on livestock and improves water-use efficiency by reducing evaporation of moisture from the soil (Salman et al. 2019). Root systems of trees can mobilize water and nutrients from larger soil volumes; at the same time, trees increase water infiltration and retention with positive effects during drier conditions. During extreme rainfall events trees' higher evapotranspiration rate helps to aerate soils (Verchot et al. 2007). At the landscape and global scale, agroforestry has positive effects on biodiversity conservation and watershed management (Lasco et al. 2014) by, for example, providing habitat for pollinators. Agroforestry has the potential to be suitable for marginal environments like saline soils (Dagar and Minhas 2016) and to rehabilitate degraded land (Saqip et al. 2019). In addition, trees on farms can be sold during a crisis (Lasco et al. 2014), increasing economic security.

Finally, agroforestry holds significant promise both for climate change mitigation and poverty alleviation. The IPCC (2018) cited 18 countries where farmers have integrated trees into their cropland, including restoring over 5 million hectares of land through farmer-managed natural regeneration in the Sahel region alone (IPCC 2018). Addressing some of the key barriers to agroforestry could help scale up this pro-poor measure substantially, including improved recognition of community tenure rights, giving greater voice to women farmers, strengthening agroforestry value chains, adaptive planning, and community-to-community capacity building.

Water management

Farm-level water management occurs along a spectrum of options, ranging from fully rainfed to entirely irrigated production (Molden 2007). Along the continuum, on-farm practices can include water storage in the soil (e.g., through water harvesting, cover cropping, or mulching); the addition of irrigation to rainfed production systems to enhance crop production (either to parts of fields or for supplemental purposes); and fully irrigated systems (where additional water permits multiple uses that include incorporating aquaculture and livestock into crop production; Molden 2007).

While expanding the use of irrigation is centrally important to climate change adaptation, upgrading rainfed agricultural practices is equally, if not more, pressing. Rainfed production systems account for over 70 percent of the world's harvested cropland and 55 percent of the gross value of food (Molden 2007), and are particularly important for the poorest and most vulnerable farmers. With existing irrigation water withdrawals already causing stress in many major river basins (Molle et al. 2007) and aquifers, some argue that there is little room for further expansion of large-scale irrigation (Rockström et al. 2010).

Rainwater harvesting—which encompasses a variety of simple and low-cost water management practices that capture and collect rainfall—holds particular promise (Mekdaschi and Liniger 2013; Critchley and Gowing 2012). These practices include planting pits (*zaï*); raised half-moon-shaped earthen barriers (demi-lunes); and lines of stone, earthen barriers, or trenches along contours. Studies have shown yield improvements from 500 to 1,000 kilograms per hectare from rainwater harvesting, depending on other factors such as soil fertility management (Hassane et al. 2000; Sawadogo 2013; Mazvimavi et al. 2008). These practices also help farmers become more resilient in the face of changes in rainfall patterns.

Fertilizer microdosing

Microdosing—which involves applying a small amount (e.g., a capful) of fertilizer to crops when rains fall or during planting—can complement the practices described in the section above. In this way, farmers can ensure that expensive fertilizer goes as far as possible while minimizing waste (assuming the inputs are affordable). For example, small-scale farmers in Mali, Burkina Faso, and Niger have used fertilizer microdosing to obtain increases in sorghum and millet yields of 44–120 percent, also increasing family incomes (Aune and Bationo 2008; Vanlauwe et al. 2010).

Soil and water management techniques are complementary. Agroforestry increases soil nitrogen and organic matter, while retaining water in soils. Water harvesting further improves soil moisture and recharges groundwater. These techniques prepare the soil for fertilizer microdosing, maximizing the fertilizer's efficiency to boost yields (Sawadogo 2013).

Soil carbon sequestration

Although much hope has been placed on sequestering carbon in agricultural soils, recent literature indicates that it is more difficult to achieve than previously thought (Powlson et al. 2016; Powlson et al. 2014; van Groenigen et al. 2017). Recent studies that measure soil carbon at deep soil depths show that no-till farming may only slightly reduce soil carbon losses, if at all. If a soil amendment (e.g., mulch, crop residues, manure) comes from outside a farm, it may add carbon to soils on that farm but at the expense of diverting that carbon from uses elsewhere (e.g., animal feed), which must then be replaced, negating the carbon benefit. In addition, building soil carbon requires large quantities of nitrogen to enable microorganisms to convert decaying organic matter to soil organic carbon. However, in Africa, nitrogen is insufficient even for crop needs, and lack of nitrogen probably limits soil carbon buildup elsewhere (Kirkby et al. 2014). At the same time, widespread use of fire in some agricultural systems, sometimes two or three times a year, significantly decreases humus content and results in net carbon loss. For example, in India, areas often burned twice a year after rice and wheat harvests, essentially are devoid of soil carbon and nitrogen (Bhuvaneshwari et al. 2019). These depleted soils have greater capacity to sequester carbon through improved land management practices not involving use of fire. The best strategy is to direct efforts toward no-regret actions listed elsewhere in this section that stabilize or build soil carbon while providing additional benefits:

- Avoid conversion of forests and other carbon-rich ecosystems
- Increase crop and pasture productivity, which adds soil carbon in roots and residues
- Use agroforestry, which adds above-ground carbon
- Eliminate or reduce routine use of fire except where unavoidable, such as to combat fungal or other pest infestations

- Pursue targeted efforts to sequester soil carbon, despite the challenges discussed above, in places where food security depends on higher soil fertility.

Reduce Enteric Fermentation

Mitigation

Ruminant livestock are responsible for roughly half of global agricultural production emissions. The largest source of these emissions is “enteric methane,” generated by ruminants as they digest grasses and plants. Increasing the productivity of ruminants addressed earlier in this section can reduce methane emissions per animal, because productivity improvements increase the amount of milk and meat produced per unit of feed. Additional strategies to reduce enteric methane emissions rely on approaches to manipulate microbiological communities in ruminant stomachs and include vaccines, selectively breeding animals that produce fewer emissions, and feeds, drugs, or supplements that can be incorporated into animals’ diets. The impact on farmers will depend on the method applied.

While no direct adaptation benefits are associated with reducing enteric fermentation through feed supplements, there may be adaptation benefits if improved animal breeding that leads to lower methane emissions also produces animals tolerant to a variety of climate stresses. From a mitigation standpoint, this option is important to consider as enteric fermentation is such a large contributor to agricultural emissions, particularly methane emissions.

Improve Manure Management

Mitigation Adaptation

Improving manure management can address a range of environmental pollution, human health, and nuisance concerns, while reducing GHG emissions. Managed manure (when animals are raised in confined settings in larger facilities) generates both methane and nitrous oxide emissions. “Dry” systems, in which farmers attempt to dry out manure before storage, can reduce emissions (IPCC 2006). In addition, separating liquids from solids in “wet” systems has potential for reducing emissions. Separation technologies range from simple gravity systems to sophisticated chemical treatments. They also reduce hauling costs and make manure more valuable as fertilizer. Digesters capture methane emissions from manure for energy use, and these include both high-technology larger machines that produce electricity at scale, and also simpler household versions. Digesters can help reduce emissions from manure managed in “wet” systems, and safeguards should be put in place to minimize methane leakage. Subsidizing smaller scale biodigesters for energy or heat for small-scale farmers can improve access. Increases in feed efficiency (addressed earlier in this section) could also lead to modest reductions in nitrous oxide emissions.[8]

Improve Soil Fertility

Mitigation Adaptation

Improving soil fertility (as well as water retention) through natural means, such as improved manure management, composting, no-burn approaches, (including no-till agriculture), and other methods can improve the yields and thus the resilience of farmers. Increasingly severe storms and droughts that increase erosion put soil fertility at greater risk, so measures to improve it become even more important from a resilience perspective.

Synthetic fertilizer use can also increase farmers’ yields and help build resilience. However, synthetic fertilizers applied to crops and pastures were largely responsible for roughly 13 percent of agricultural production emissions in 2011 (FAO 2019), although manure and other sources can also contribute to a lesser degree. More than 90 percent of emissions from fertilizing soils result from manufacturing, transporting, and applying nitrogen.

Increasing food production implies a growing demand for fertilizer and higher associated emissions and pollution. How much higher depends on how efficiently crops use nutrients. There is much room for improvement: today, crops worldwide absorb less than half the nitrogen added to farm fields (Zhang et al. 2015; Lassaletta et al. 2014). The remainder runs off the fields and causes water pollution, or escapes into the air, causing air pollution, including the potent GHG nitrous oxide. Rates of nitrogen fertilizer application per hectare, and the percentage of nitrogen absorbed by crops (called “nitrogen use efficiency” or NUE), varies greatly across countries and individual farms. At one extreme, farmers in most countries in sub-Saharan Africa use little fertilizer, and the fertilizer they use is well-absorbed by crops, while at the other extreme, farmers in China and India generally overapply fertilizer with low absorption by crops (Zhang et al. 2015).

Farmers can increase NUE and reduce overall fertilizer use by applying fertilizer frequently and in perfectly required amounts over the course of a growing season. However, such intensive management is usually too expensive and impractical. Therefore, innovations are required, and farmer awareness of more sustainable practices will need to be raised. Nitrification inhibitors and other "enhanced efficiency" fertilizers can increase NUE, reduce nitrous oxide emissions, and increase yields. Biological nitrification inhibition is another promising option for crops and pasture grasses.

Improve Rice Management

Mitigation Adaptation

Rice is a staple crop for roughly half of the world's population (FAOSTAT n.d.). Yet climate change is increasingly threatening rice supply. Most rice is produced in flooded fields (paddies), and the flooding blocks oxygen from penetrating into the soil, which allows archaea, a single-celled organism that produces methane, to thrive.

There are good opportunities for improving rice management, which can have both adaptation and mitigation benefits. Adaptation benefits include saving water and making the most of scarce water supplies; for example, the practice of alternate wetting and drying has the potential to save up to 30 percent of water, thus buffering for droughts and drier years (Richards and Sander 2014). Studies of a system of rice intensification demonstrate increased water productivity, water-use efficiency, drought and storm resistance as well as resistance to colder temperatures (Uphoff and Thankur 2019). In addition, reducing methane emissions may benefit production because this gas is a precursor to tropospheric ozone, which reduces rice yields (Carter et al. 2017). A switch to flood-tolerant rice in India has shown to increase yields by 45 percent over popular varieties during flood conditions (i.e., 10 days of submersion; Dar et al. 2013). In Bangladesh, flood-tolerant rice varieties have had significant positive impacts on adopters' farm profits and consumption expenditure compared to those of nonadopters (Bairagi et al. 2018). This same study highlights that adoption of flood-tolerant rice varieties has yet to reach optimal scale largely due to a lack of access to information.

Available research suggests high technical potential to mitigate rice emissions, and most mitigation options also offer some prospect of economic gains through higher yields and reduced water consumption. Provided the enabling environment is supportive (Section 3), four main suboptions for farmers include:

- *Accelerating rice yield growth.* Methane emissions are closely tied to the area under rice paddies, so accelerating yield growth can maintain or reduce total paddy area, reducing emissions.
- *Removing rice straw.* Adding fresh rice straw to flooded fields increases methane production. Straw may instead be used for other productive purposes such as bioenergy.
- *Reducing flood periods.* Reducing or interrupting flooding reduces growth of methane-producing bacteria. Farmers can also plant rice initially into dry rather than flooded land. Reducing flooding can reduce methane emissions by up to 90 percent (Joshi et al. 2013). In China and Japan, farmers usually draw down water at least once per season because it increases yields (Itoh et al. 2011), though these yield benefits have not been found in the United States.
- *Breeding lower-methane rice.* Some varieties emit less methane than others, and researchers have shown promising potential in experiments (Su et al. 2015), but methane-inhibiting traits have not been bred into the most commercial varieties (Jiang et al. 2017).

These opportunities, in particular, can benefit small-scale rice farmers as well, but incentive structures matter: small-scale farmers need adaptation support and social safety nets that are equally available to women and marginalized groups, and any mitigation incentives should demonstrably benefit and not harm small-scale producers. If the primary sources of emissions are widely distributed across many small-scale producers, it is critical to identify support and other incentives that benefit the livelihoods of small-scale farmers in order to scale up mitigation efforts.

Support Agricultural Energy Efficiency and Increased Access to Nonfossil Energy Sources

Mitigation Adaptation

Energy emissions from fossil fuel use account for more than 20 percent of global agricultural production emissions (Searchinger et al. 2019). As in other sectors, increasing energy efficiency and use of renewable energy can lower agricultural energy emissions. A few studies have found potential for efficiency gains, such as a study in India that assessed use of alternative water pumps (Saini 2013) or another in Africa that looked at methods to dry cassava (CGIAR 2016). Solar and wind power can provide heat and electricity. Reducing diesel fuel use will be more difficult and may need to rely on a transition to fuel cells using hydrogen power. Subsidies can help to provide necessary support for small-scale farmers to implement technologies. Renewably generated hydrogen could also reduce emissions from synthetic fertilizer production, which is currently very energy-intensive.

Link Productivity Gains with Protection of Natural Ecosystems to Avoid Deforestation

Mitigation Adaptation

Although productivity gains are critical to sustainable intensification and achieving food security while reducing the need for agricultural land expansion, they may also increase profitability, which may also encourage further conversion of natural landscapes. If farmers and the world are to benefit from productivity gains while also protecting forests and other remaining natural ecosystems, efforts to increase productivity while protecting ecosystems must be explicitly linked. Fortunately, REDD+ safeguards already exist to help address this. This can be complemented in NDCs through support for ecosystem-based adaptation (Box 3) and recognizing the need to keep ecosystems healthy in order to provide the full range of ecosystem services, such as food and fiber, as well as homes for pollinators; local climate and watershed regulation; and cultural and social benefits. Where farmers have clear land tenure, governments can support agricultural improvements on existing farmland to build social support for enforcement of ecosystem protection. Governments can also designate natural areas and enter into joint management agreements with indigenous peoples and local communities to help curb deforestation (Stevens et al. 2014; Gibbs et al. 2016; Jackson 2015).

Box 3 | **Ecosystem-Based Adaptation**

Integrating ecosystem-based adaptation measures into NDCs can be an effective way of helping people adapt to the adverse effects of climate change. The Convention on Biological Diversity defines ecosystem-based adaptation as "the use of biodiversity and ecosystem services as part of an overall adaptation strategy" (Convention on Biological Diversity 2018). This type of adaptation action depends on maintaining ecosystem services, which are the benefits that people obtain from ecosystems (MEA 2005).

These include

- provisioning services, such as food, water, timber, fiber, and genetic resources;
- regulating services, such as modification of climate, water flows, disease prevalence, and water quality;
- cultural services, such as recreation, aesthetic enjoyment, and spiritual fulfillment; and
- supporting services, such as soil formation, pollination, and nutrient cycling (MEA 2005).

Reforest Abandoned, Unproductive, and Liberated Agricultural Lands—Including Peatlands

Mitigation Adaptation

When land is abandoned by agriculture, natural ecosystems typically regenerate, and governments can also assist the regeneration process by incentivizing tree planting. Planting with the goal of re-establishing diverse forests confers greater biodiversity, ecosystem services, and climate benefits than single-species forest plantations. Reforestation of degraded lands can help to decrease the risk of erosion and landslides, which may otherwise increase in a changing climate due to more intense downpours, often alternating with longer, harsher droughts. Reforestation can also help to regulate and maintain water supplies by reducing evapotranspiration and drying of landscapes.

As noted in the Intergovernmental Panel on Climate Change (IPCC) Special Report on Climate Change and Land (IPCC 2019), reforestation must not compete with food security and livelihoods. In the meantime, reforestation should generally be limited to lands that are low-yielding and also demonstrate low potential for agricultural improvement. In addition, determining whether land is actually "abandoned by" or "liberated from" agriculture must be done in a way that does not compromise food security or resource tenure of rural poor and indigenous populations.

The world's 26 million hectares of drained peatlands—a relatively small area that is nevertheless responsible for about 2 percent of global annual GHG emissions—are a high immediate priority for restoration (Biancalani and Avagyan 2014). Many of these drained peatlands have low farming intensity or are only used for grazing. Blocking drainage ditches and canals can allow "rewetting" of peatlands and typically eliminates emissions. Beyond restoration, conservation of remaining peatlands should be a high priority. More broadly, in order to keep warming below 1.5°C, the world will need to reforest at least 585 million hectares of land by 2050 (Searchinger et al. 2019).

Reduce Food Loss and Waste

Mitigation Adaptation

Approximately one-third of food produced annually is lost or wasted between the farm and the fork (FAO 2015). Food loss and waste results in nearly $1 trillion in economic losses across the globe (FAO 2015). Food loss and waste can contribute to food insecurity, is a waste of agricultural land and water resources, and is responsible for about a quarter of all agricultural GHG emissions (FAO 2015).

A number of strategies can reduce postharvest losses and increase farmer incomes and resilience (FAO 2016c). These include improved harvesting and food storage techniques and equipment, energy-efficient cold chains, and more agroprocessing. Low-technology options like evaporative coolers and low-cost plastic storage bags can help in areas where farmers lack electricity or means to invest in refrigeration. Improved infrastructure (e.g., roads, electricity) and access to markets can also reduce losses and support more access for smaller and more remote farmers. In developed countries, reducing food waste relies more on "nudges" that change consumer behavior, such as simplifying product date labels or reducing portion sizes. Governments can also incentivize retailers to donate unsold food to charities. The United Kingdom used a combination of these strategies to reduce household food waste by 21 percent between 2007 and 2012 (Lipinski et al. 2013).

Shift to Healthier and More Sustainable Diets

Mitigation

As incomes rise above poverty levels and people move to cities, diets tend to become more varied and also higher in sugar, fats, refined grains, and animal-based foods. Although some of this shift can initially be beneficial for nutrition, a further shift toward unhealthy diets has led to more than 2 billion adults being overweight or obese, increasing the burden of diet-related noncommunicable diseases (Willett et al. 2019). And although modest consumption of meat and dairy can supply critical micronutrients, convergence in diets toward high levels of meat consumption common in wealthy countries would make it harder for the world to feed a growing population while reducing GHG emissions.

Consumption of animal-based foods is projected to rise 70 percent between 2010 and 2050, with a near 90 percent increase in consumption of ruminant meats (from cattle, sheep, and goats). However, animal-based foods—and ruminant meats in particular—are more resource-intensive than plant-based foods. Beef, for example, requires 20 times the amount of land, and emits 20 times the GHGs, per gram of protein compared with pulses such as beans or lentils (Searchinger et al. 2019). Therefore, in high-income countries, a shift from high-meat diets toward plant-based foods—specifically a nutritious mix of whole grains, fruits, vegetables, nuts, and legumes, while limiting refined grains and sugars—can be beneficial for both human health and the climate (Willett et al. 2019).

In the United States and Europe, per capita beef consumption has fallen by more than one-third since the 1970s while chicken consumption has grown, suggesting that large population-wide shifts in dietary preferences are feasible (FAOSTAT n.d.). These shifts can be encouraged by investing in development of meat substitutes (e.g., plant-based meats, blended meat-plant products), improved marketing of plant-based foods and plant-rich dishes, and government policies supporting changes to food procurement practices, national dietary guidelines that consider both nutrition and environmental sustainability, regulations that shape the consumption environment (e.g., how food can be marketed or displayed), and changes to food subsidies and taxes (Ranganathan et al. 2016). While no current NDC references the importance encouraging shifts to healthier and more sustainable diets, this action warrants consideration due to the significant mitigation potential.

Avoid Competition from Bioenergy for Food Crops and Land

Mitigation Adaptation

Some studies have suggested that biofuel cultivation can result in new agricultural jobs, higher farm wages, and diversified farmer income streams. However, it is unclear whether these livelihoods would add to or displace conventional jobs growing food crops, and what the effects on small-scale farmers would be.[9]

More fundamentally, "modern" bioenergy is mainly produced from feedstocks grown on dedicated land, which increases global competition for finite land. The IPCC Special Report on Lands found that overall, bioenergy expansion tended to compromise adaptation efforts due to competition for land and water resources (IPCC 2019). Increasing land competition means those facing insecure tenure rights and food insecurity can find their land and livelihoods at risk—and it also makes it harder for the world to feed a growing population without clearing more forests.

Claims that modern bioenergy reduces GHG emissions rely on the assumption that bioenergy is inherently "carbon-neutral"—and do not count the carbon emitted by burning plants under the assumption that the plants will regrow later and absorb that carbon.

Dedicating land to bioenergy production comes at the cost of not using that land for other purposes, including production of food, feed, and timber—or carbon storage. A limited amount of low-carbon bioenergy is available from feedstocks that do not come from dedicated land, such as wastes and residues. However, claims of large bioenergy potential to reduce GHG emissions—including for "bioenergy with carbon capture and storage (BECCS)"—ignore underlying land tenure as well as the alternative uses of land (e.g., food production and carbon storage), in effect assuming lands dedicated to bioenergy can continue to serve these other needs simultaneously (Searchinger et al. 2017).

The phase-out of subsidies and mandates currently in place for bioenergy that is grown on dedicated land can help to address this issue, along with the correction of flawed accounting in laws that treat bioenergy as inherently "carbon-neutral." Of course, shifts away from bioenergy production should not impede shifts away from fossil fuels.

Reduce Agricultural Sector Use of Fire

Mitigation Adaptation

In agriculture, biomass burning involves the burning of crop, pasture, and forest residues, either to remove unwanted plants or to redirect animals to alternative grazing land for land clearing purposes. Open burning emits both GHGs and air pollutants, which are significant in terms of their regional impacts. For example, in Africa, intentional burning of savanna accounts for 25 percent of total agricultural emissions (Tubiello et al. 2013). In southeast Asia, fires in drained tropical peatland, often linked to palm oil cultivation, can lead to significant emissions peaks in specific years, with impacts seen at large regional and even global scales (Hayasaka et al. 2014). In India, burning agriculture residue in the northwestern states not only impacts air quality in Delhi and neighboring areas, but also affects central and southern Indian states and the eastern parts of the Indo-Gangetic Plains (Rana et al. 2018).

Land clearing associated with open burning to permanently convert forests to agriculture also reduces existing carbon sinks. Open burning is the largest source of black carbon and contributes to fine particulate matter (PM2.5) pollution. As described in Annex 1, PM2.5 emissions cause respiratory disease and premature mortality and impacts crop yields by limiting photosynthesis.

For some farmers, it may be easier and cheaper to burn residues and grass, even if it is not a good long-term strategy. Farmers may not have the equipment, labor, or resources to plow residues into the soil, grow cover crops, dig residues into their fields, or adopt other practices that are better for long-term soil fertility and soil conservation than burning. They may not have enough labor to cut bush and pull weeds by hand. In some regions, however, even large-scale farmers burn residues. The practice remains widespread in the former Soviet Union, where farmers report that poor quality steel leads to fears that plowing through stubble may lead to equipment breakage (Bellona and Yabloko 2010). Burning fields saves immediate labor or equipment costs, and the decrease in yields is not seen especially where overuse of fertilizer (often subsidized) offsets this loss in fertility.

The myth also persists that burning "enriches" the soil. Even in the short term, however, burning destroys soil structure and humus, and over the long-term leads to erosion and soil loss. The long-term consequences of agricultural biomass burning include changes in vegetation, eutrophication of local waterways from soil and fertilizer run-off, and potentially even desertification, leading to enhanced vulnerability during extreme climate events (ICCI 2019). Thus, while farmers might use fire for immediate short-term gain, over time this practice proves harmful to crop yields and enhances food insecurity. Extension services to educate farmers on the actual impacts of burning and on alternative methods, as well as supporting purchase of no-burn equipment as part of the normal replacement cycle, can break this pattern far more effectively than inefficient "bans." Farmers can also use residues for other economic benefits, such as a source of energy when made into pellets or for biofuel, or other emerging markets in addition to traditional use as livestock feed or bedding.

5. AGRICULTURAL CONTRIBUTIONS FOR ENHANCED NDCs

This section offers practical options for incorporating agriculture into an enhanced NDC.

Many options are available, which are not mutually exclusive. Depending on national circumstances and priorities, some countries may choose to strengthen the implementation of existing agricultural climate policies and targets (including support needs); add specific policies and actions to build resilience and enhance adaptation; add specific policies and actions to reduce emissions; incorporate additional agriculture-sector action into an emissions target; or include additional information to improve understanding.

The examples provided in this section are illustrative and nonexhaustive, drawing from the content presented in Sections 3 and 4. Some solutions will not be relevant or feasible everywhere. Policymakers will need to decide which actions and approaches are relevant for their agriculture sector.

Strengthen Implementation

All countries have an opportunity to include new actions or measures in their NDCs to strengthen implementation, such as strengthened governance arrangements, more inclusive processes, or the introduction of mechanisms aimed at mobilizing finance for NDC implementation. Including certain measures and actions could also support greater alignment with a country's sustainable development objectives under the 2030 Agenda for Sustainable Development (Fransen et al. 2017).

Section 3 describes the importance of an enabling policy environment to foster productive, resilient, and inclusive farming practices. This environment can help strengthen the implementation of existing agricultural climate policies and targets and set the stage for enhanced action. Drawing from the content in Section 3, the following are examples of possible actions that can be included in an enhanced NDC to strengthen implementation of adaptation or mitigation measures:

- Aligning agricultural climate targets, policies, and actions with NAPs, NAPAs, NAMAs, SDGs, or biodiversity targets
- Strengthening MRV systems for better inventories, assessments of mitigation potential, assessments of climate risks, or access to finance
- Improving agricultural extension
- Redirecting agriculture support in a manner that supports long-term sustainable, climate-mitigating, climate-resilient food production
- Supporting equality and inclusivity
- Identifying rights-based and gender-responsive measures, including assessing the differential impacts of actions in the agriculture sector on male and female farmers
- Allocating resources directly to women small-scale farmers
- Identifying policies and measures to equitably clarify land tenure and protect small-scale farmers
- Identifying funding to support actions as well as safeguard measures to minimize adverse impacts
- Identifying and/or prioritizing actions that support both mitigation and adaptation outcomes
- Describing support needs
- Describing additional cobenefits resulting for mitigation and/or adaptation actions

Add Specific Policies and Actions

Including priority climate policies and actions in an enhanced NDC can also be helpful for providing more detail on the means of reaching climate goals and to mobilizing support for these activities.

Specific policies and actions to build resilience and enhance adaptation

Drawing from the content in Sections 3 and 4, the following are examples of possible policies and actions that can be included in an enhanced NDC to build resilience and enhance adaptation:

- Promoting diversification into more climate-resilient types of crops and livestock
- Greater use of digital communication technologies such as critical weather information and seasonal forecasts
- More support for farmer-to-farmer education and enhanced data and analytics to improve disease surveillance and provide early warning of pest outbreaks
- Enhancing social safety nets to provide protection
- Making weather-based and other types of crop insurance more accessible to small-scale farmers
- Expanding microfinance and better integrating risk reduction and resilience-building

Specific policies and actions to reduce emissions

Drawing from the content in Section 4, the following are examples of possible policies and actions that can be included in an enhanced NDC to reduce emissions:

Box 4 | **Black Carbon Targets and NDCs**

Countries can set targets to reduce black carbon in their NDCs, but these should be reported and accounted for separately from GHG emissions since black carbon is not a pollutant covered under the United Nations Framework Convention on Climate Change. As noted earlier, black carbon accounting and warming uncertainties also remain high—carbon dioxide and black carbon impact the climate in different ways and have very different lifetimes; there is yet to be scientific consensus on appropriate metrics to equate the two. This should be noted explicitly in the NDC. Accordingly, black carbon targets should be in mass units, not in carbon dioxide equivalent (CO_2e) units.

Source: Ross et al. 2018.

- Increasing productivity—for crops and livestock and on pasture
- Improinge soil and water management
- Reducing enteric fermentation
- Improving manure management
- Improving soil fertility
- Improving rice management
- Supporting agricultural energy efficiency and increased access to nonfossil energy sources
- Linking productivity gains with protection of natural ecosystems to avoid deforestation
- Reforesting abandoned, unproductive, and liberated agricultural lands, including peatlands
- Reducinge food loss and waste
- Shifting to healthier and more sustainable diets
- Avoiding competition from bioenergy for food crops and land
- Reducing agricultural sector use of fire

Incorporate Additional Agriculture-Sector Action into an Emissions Target

Additional agriculture-sector action can be integrated into an economywide emission reduction target or can be presented as a separate sector target. From a mitigation perspective, an economywide emissions target generally offers the most flexibility for countries on how to achieve emissions reductions, because it does not specify which actions will drive emissions reductions unless supplemented with additional detail (Levin et al. 2015). However, to support transparency and accountability, and to drive targeted abatement in the agriculture sector, countries that currently have economywide emissions targets could consider incorporating specific actions and/or a sector-specific emissions target in their enhanced NDC.

Economywide emissions target

There are two options available to incorporate agriculture-sector action into an economywide emissions target:

- strengthen an existing economywide emissions target to include additional mitigation action in the agriculture sector; or
- create a new economywide emissions target that includes ambitious mitigation action in the agriculture sector.

In both cases, the enhanced NDC should clearly state that the agriculture sector is included in the economywide emissions target.

Sector-specific target

There are additional options to include sector-specific emissions targets, such as:

- strengthen or create an ambitious, agriculture-specific emissions reduction target (e.g., reduce emissions from the agriculture sector)
- strengthen or create an ambitious, agriculture-specific, emissions-specific target (e.g., reduce methane emissions or nitrous oxide emissions from the agriculture sector)

Facilitate Clarity, Transparency and Understanding

Providing additional context and information to facilitate clarity, transparency, and understanding is also recommended. This should not create additional burdens to countries. Rather, it is simply an exercise to document the assumptions and processes involved in enhancing the NDC. This is also a good opportunity to describe clearly how the agricultural climate policies and actions that will be pursued will benefit the most vulnerable communities and small-scale farmers.

6. CONCLUSION

Enhanced NDCs, to be submitted to the UNFCCC ideally by 2020, can help to capture the action that is possible and required to transform the agriculture sector. As demonstrated throughout this paper, a focus on agriculture in the context of enhancing the ambition of NDCs has the potential to deliver significant emission reductions while improving resilience. This paper has shown a number of options that policymakers have available to enhance their NDCs in ways that can benefit farmers, the environment, and, with the right enabling environment, help rural communities—especially vulnerable populations and women—not only survive but thrive.

ANNEX 1: FRAMING THE AGRICULTURE SECTOR

This Annex provides an overview of the agriculture sector's vulnerability to climate change and its greenhouse gas emissions. It draws on recent research, particularly the IPCC special report *Climate Change and Land* (IPCC 2019), which compiles the latest evidence on the vulnerability of land and food to climate change, as well as the imperative for mitigation within these sectors.

Climate Change Impacts on Agriculture and Food Security

The IPCC (2019) found that observed climate changes are already posing risks to agriculture. The global temperature over land was 1.4°C warmer in the period 1999–2018 compared with 1881–1900. Heat-related events and heavy precipitation events have increased in most regions of the world, and drought frequency and intensity have increased in some regions, including Africa, northeast Asia, west Asia, and parts of South America. Droughts have become more pervasive in drylands, with the area experiencing drought increasing by 1 percent per year between 1961 and 2013 (IPCC 2019).

These climatic changes are impacting and will continue to impact how and where food is produced around the world (Box A-1). Pastoral livestock systems have experienced reduced productivity, poor animal health, and more limited access to water and feed (IPCC 2019). Yields of corn and wheat have declined in many low-latitude regions (IPCC 2019). A counter-factual analysis estimated that global yields of corn, wheat, and soybeans were 4 percent, 2 percent, and 5 percent lower, respectively, than they would have been in the absence of climate change from 1981–2010 (Iizumi et al. 2018). Food security has been impacted in the drylands of Africa and high mountain regions of Asia and South America (IPCC 2019).

From a gas and pollutant perspective, short-lived climate pollutants (SLCPs) such as methane, tropospheric ozone, and black carbon affect agricultural production through direct effects on crops and indirect effects on climate. Increased carbon dioxide (CO_2) could reduce crops' content of protein (Myers et al. 2014) and various micronutrients like zinc, magnesium, or iron (Erbs et al. 2010; Fernando et al. 2012; Högy et al. 2009).

Impacts are expected to become more severe as temperatures continue to rise. The IPCC (2019) found that impacts on crop production will vary by region with the worst impacts in the tropics and subtropics. Globally, yields of wheat, corn, and rice could be reduced by 10–25 percent for each degree of global mean surface temperature increase (Deutsch et al. 2018). Impacts on livestock production are expected to be detrimental overall, with regional variability: productivity increases have been projected for the United States and Canada and significant declines for sub-Saharan western Africa and Australia (IPCC 2019). Crop and livestock productivity declines are projected in drylands, which comprise more than 40 percent of the Earth's surface.

Climate change affects all dimensions of food security: food availability, access to food, utilization of food, and stability of food supply (FAO 2016c). Risks of food instability, drought, and water stress, among other impacts, are projected to worsen between 1.5°C and 2°C of warming. More frequent extreme weather events could reduce the stability of the global food supply. Rising food prices due to climate change may increase the risk of food insecurity and hunger. For example, one modeling scenario projected a median increase in cereal prices of 8 percent in 2050 due to climate change.

Climate change could also exacerbate land-use conflicts as biomass is used for mitigation. In the absence of action to limit the global temperature rise to 1.5°C, climate change could place millions more at risk of hunger and undermine efforts to eradicate poverty. These threats to global food security are growing at the same time as food demand continues to rise and hunger and malnourishment persist (Carter et al. 2018). The number of people experiencing hunger rose for the past three years in a row to more than 820 million, after a decade of decline (FAO, IFAD, UNICEF, WFP and WHO 2019). By 2050, climate change could place hundreds of millions more at risk of hunger (IPCC 2019). Particularly vulnerable populations include smallholders, pastoralists, women, and the poor, as discussed in the main text.

Box A-1 | **Risks of Climate Change and Projected Impacts**

Risks of Climate Change on Agriculture

- Increased air and water temperatures
- Increased frequency and severity of heat waves, droughts, fires, and floods
- Decreased availability of fresh water
- Salinization of land and water
- Increase in tropospheric ozone

Projected Impacts on Crops

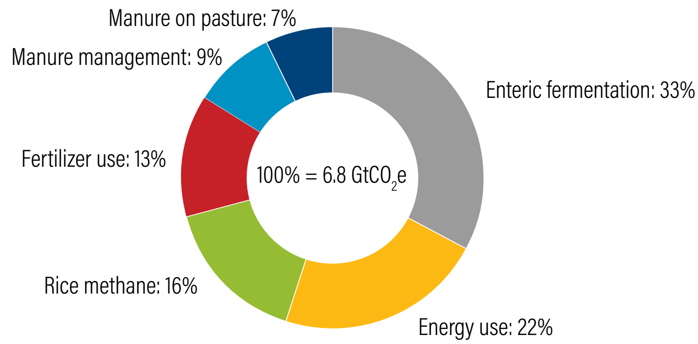
- Significant reduction in global production of wheat, rice, corn, and soybeans for each degree Celsius of global temperature rise and increased ground-level concentrations of tropospheric ozone
- Variable impacts based on different regions, with generally negative impacts in developing countries and in areas where food security is already a challenge
- Increased incidence of pests and diseases

Projected Impacts on Livestock

- Physiological changes including heat stress and high respiratory rates
- Negative effects on reproduction and feeding
- Changes to quality and quantity of livestock food
- Increased incidence of pests and diseases

Source: FAO 2016c; IPCC 2018.

Figure A-1 | **Agricultural Production Emissions, 2010**



Source: Searchinger et al. 2019.

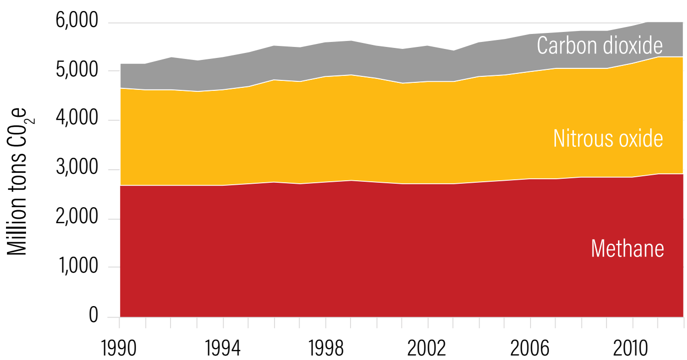
Emissions from Agriculture

Agriculture is the second largest source of global greenhouse gas emissions, although methods for calculating agricultural emissions vary significantly. Direct GHG emissions from agricultural production contribute about 13 percent of global emissions and, when adding in land-use change, the agriculture and land sector accounts for approximately 23 percent of total global emissions (IPCC 2019). Land sequesters about 11 $GtCO_2$ per year, but climate change, deforestation, and land degradation could reduce this carbon sink in the future (IPCC 2019).

Most direct GHG emissions from agricultural production come in the form of methane and nitrous oxide. Nitrous oxide is a powerful greenhouse gas primarily arising from overuse of fertilizer, especially on burned agricultural land, where loss of fertility from burned soil demands more fertilizer use. Agriculture, forestry, and other land uses contributed 44 percent of global methane emissions and 82 percent of nitrous oxide emissions between 2007 and 2016 (IPCC 2019). Methane produced from cattle belching (enteric fermentation) is the largest source, followed by energy use, methane from rice cultivation, and nitrous oxide from fertilizer use (Searchinger et al. 2019). Other significant sources include methane from manure left on some pastures and manure management in industrial-scale livestock production. The agriculture sector is also responsible for approximately 40 percent of global black carbon emissions (CCAC 2019), mainly due to open-field burning of agricultural waste.

Agriculture also contributes to emissions from land-use change as forests and other lands are cleared for farming—nearly 500 million hectares of forests and woody savannas were cleared for agriculture between 1962 and 2010 (Searchinger et al. 2019). Much of this clearing involves use of fire. In addition, routine use of fire, especially in the warmer and sometimes drier conditions of a changing climate, can lead to large bursts of emissions from wildfires and deforestation, as seen in the summer 2019 Amazon fires, most of which spread from land that was already cleared and in use for agriculture between 1962 and 2010. Searchinger et al. (2019) estimated emissions from land-use change at around 5 $GtCO_2e$ in recent years, roughly equal to 10 percent of global emissions.

Figure A-2 | **Agricultural Production Emissions, by Gas**



Note: Data include energy and nonenergy emissions from agricultural production.
Source: Data from FAOSTAT n.d.

In addition, agricultural emissions vary by region and type of producer. For example, most meat and dairy emissions come from a few countries, particularly the main exporting regions: the United States and Canada, the European Union, Brazil and Argentina, and Australia and New Zealand. These regions account for 43 percent of global emissions from meat and dairy production and are also home to the headquarters of most of the biggest meat and dairy producers (GRAIN and IATP 2018). Conversely, small-scale intensive rice production, predominately in Southeast Asia, is a considerable source of agriculture emissions in the aggregate despite being small in per capita emissions, because flooded soil encourages the production of methane (CGIAR 2019).

Agriculture emissions are growing and will likely continue to rise. GHG emissions from agricultural production grew 15 percent between 1990 and 2014 (Figure A-2), driven largely by increasing global demand for meat and other animal-based products. As nations urbanize and citizens become wealthier, people generally increase their consumption of animal-based foods. Animal-based products provide critical nutrients to the world's poor, but the global rise in consumption of meat and dairy is largely unnecessary—half of the world's population consumes much more protein than needed (Searchinger et al. 2019). Methane emissions will continue to grow because demand for animal-based foods is projected to increase 70 percent between 2010 and 2050 (Searchinger et al. 2019). Rising use of synthetic fertilizer has also contributed to growth in emissions, particularly in middle- and higher-income countries. The IPCC estimates that nitrous oxide emissions from fertilizer use rose ninefold between 1961 and 2010, and will soon become the second largest source of emissions on farms behind methane emissions enteric fermentation (Smith et al. 2014).

Recent work conducted by WRI, the World Bank, UN Environment, and UNDP projected that agricultural production emissions could reach 8 $GtCO_2e$ per year in 2030 and 9 $GtCO_2e$ in 2050 even if productivity gains keep pace with historical rates (Searchinger et al. 2019). Together with emissions from land-use change, total emissions from the sector are projected to reach 15 $GtCO_2e$ per year by 2050, a 25 percent increase over 2010 levels.[10] Emissions of this magnitude would take up 70 percent of the "emissions budget" allowable in 2050 if the global temperature increase is held to less than 2°C. Emissions from the sector will need to be cut to 4 Gt per year to remain under 2°C of warming, 67 percent below 2010 levels, and carbon removal from reforestation will be required to offset ongoing agricultural production emissions and remain under 1.5°C of warming. In sum: the world cannot meet the Paris Agreement climate goals without reducing emissions from agriculture and land-use change.

ENDNOTES

1. "Directed" in this instance is a deliberate analysis and multistakeholder consideration of opportunities to advance national agricultural climate action, including feasibility of implementation, the results of which can be included in an enhanced NDC.
2. See Searchinger et al. (2019) for a comprehensive list of mitigation actions in the food and agriculture sector, including additional actions like improving fisheries and aquaculture, and double-cropping. See Bapna et al. (2019) for a summary of the most significant agricultural adaptation options.
3. In addition, the value of cash crops tends to be disproportionately captured and concentrated by wealthier landowners, traders, and retailers, and conversion of land from forest communities and small-scale farmers to support large-scale commodity production is associated with a disproportionate share of emissions as well as tenure and human rights disputes (e.g., Willoughby and Gore 2018).
4. Impacts close to the equator may be most severe where yields are already relatively low, mostly due to a lack of inorganic fertilizer use (Mueller et al. 2012; van Ittersum et al. 2016).
5. For example, cocoa and rice value chains have become dominated by corporate ownership of milling and processing. See Jennings et al. (2018) and Oxfam (2018).
6. The actions focus on land-based mitigation options. Ocean-based foods and farming are not covered in this paper. Read Searchinger et al. (2019) for more information.
7. Read more at Transformative Adaptation: https://www.wri.org/our-work/project/transformative-adaptation.
8. One promising option, a compound called 3-nitrooxypropan (3-NOP), reduces methane emissions by 30 percent while potentially increasing animal growth rates (Hristov et al. 2015; Romero-Perez et al. 2015). However, because it requires daily feeding, it is not yet feasible for most grazing operations.
9. For manure left on pasture, recent advances could potentially further reduce emissions. In New Zealand, experiments have applied chemical nitrification inhibitors to pastures and (at a smaller scale) fed inhibitors to cows (Doole and Paragahawewa 2011). In Latin America, studies have found that biological nitrification inhibition is possible; manure deposited on one variety of *Brachiaria* grass was found to generate almost no nitrous oxide emissions (Byrnes et al. 2017), suggesting the potential to breed this trait into other pasture grasses.
10. IPCC 2018, p. 484. "Large-scale bioenergy production could alter the structure of global agricultural markets in a way that is, potentially, unfavorable to small-scale food producers."
11. As noted in Searchinger et al. (2019): "Bioenergy creates so much potential competition for food and carbon storage because bioenergy converts only a fraction of 1 percent of energy from the sun into usable energy. Food or energy crops also require well-watered, productive land. . . . Burning (and refining) biomass also emits more carbon per unit of energy generated than burning fossil fuels."
12. See Searchinger et al. (2019) for a complete description of this "business as usual" scenario, in which the global population grows to 9.8 billion, diets shift to include more animal-based foods, the global rate of food loss and waste is maintained at 2010 levels, crop-based biofuels' share of global transportation fuel is maintained at 2010 levels, and crop and livestock productivity grows at roughly the same levels as during the period 1962 to 2006.

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Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

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We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of governments, businesses, and communities combine to eliminate poverty and sustain the natural environment for all people.

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