Ceres2030
Sustainable Solutions to End Hunger

CHAPTER 5

How We Plan to Integrate Environmental Sustainability

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INTRODUCTION

The United Nations has tasked the global development community with a set of sustainable development goals (SDGs) to provide a vision for a sustainable future. The second goal (SDG 2) aims at ending hunger, achieving food security and improved nutrition, and promoting sustainable agriculture. The focus of the Ceres2030 project is to provide timely and actionable policy recommendations on costs, interventions and spending allocation for achieving the SDG 2 sub-targets 2.1, 2.3 and 2.4.

This technical note explains how the Ceres2030 model integrates SDG 2.4 through practical, effective and transparent metrics based on available data. The 2030 Agenda for Sustainable Development defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Sustainability is defined across three pillars: economic development, social development and environmental protection. (World Commission on Environment and Development, 1992)

While all three dimensions are important, this technical note will justify and explain the Ceres2030 model's focus on the measurement of the environmental dimension for SDG2.4, since the economic and social dimensions of sustainability are already tracked and embedded in the framework of the model. The environmental dimension is key to Ceres2030's costing estimates and optimal spending recommendations because environmental sustainability may be particularly negatively impacted by the expansion of food production and consumption required to end hunger and double the productivity and incomes of small-scale food producers. Environmental sustainability also includes a number of externalities and other missing market challenges (factors that prevent a market's operation), for example relating to greenhouse gas (GHG) emissions or water quality and use. Additional efforts are needed to quantify these challenges in the model.

We cannot yet rely on the guidance from the United Nations for indicators to track progress on SDG 2.4 because they are still in development and under negotiation. This note outlines how we define and model environmental sustainability in the meantime, until official indicators for SDG 2.4 are available. In Section 2 we discuss current proposals for how to measure SDG 2.4 and give our reasons for the environmental indicators we have chosen. In Section 3 we explain how these indicators are incorporated in the model. In Section 4 we discuss how our portfolio of agricultural interventions is expected to interact with these indicators (see Technical Note 1.1.a).

SDG 2.4 CONTEXT

We start this section by providing the SDG 2.4 definition and proposed UN indicators. Then we identify how our modeling framework tracks the various dimensions of sustainability.

WHAT IS SUSTAINABILITY IN AGRICULTURE?

SDG 2.4 states:

> By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding, and other disasters and that progressively improve land and soil quality (United Nations, 2018).

The UN-defined indicator for SDG 2.4 is 2.4.1 (United Nations, 2018): "The proportion of agricultural area under productive and sustainable agriculture."

The custodian institutions for this indicator are FAO & UNEP. The UN uses a three-tier approach to classify SDG indicators (United Nations Statistics Division, 2018):

> "Tier 1: Indicator is conceptually clear, has an internationally established methodology and standards are available, and data are regularly produced by countries for at least 50 per cent of countries and of the population in every region where the indicator is relevant.
>
> "Tier 2: Indicator is conceptually clear, has an internationally established methodology and standards are available, but data are not regularly produced by countries.
>
> "Tier 3: No internationally established methodology or standards are yet available for the indicator, but methodology/standards are being (or will be) developed or tested."

Recent developments have allowed researchers to reclassify SDG 2.4 from a Tier 3 to a Tier 2 indicator. Before they can make a further reclassification to Tier 1, the committee is waiting for the results of several pilot studies and additional testing.

It is a challenge to build a single indicator to track sustainable agricultural production, given the many dimensions of the concept.

FAO (1988) defined agricultural sustainability as:

> The management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such development (in the agricultural, fisheries and forestry sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable.

FAO built on this definition in 2014, outlining five principles of sustainable agriculture (FAO, 2014):

1. Improving efficiency in the use of resources is crucial to sustainable agriculture.
2. Sustainability requires direct action to conserve, protect, and enhance natural resources.
3. Agriculture that fails to protect and improve rural livelihoods, equity, and social well-being is unsustainable.
4. Enhanced resilience of people, communities, and ecosystems is key to sustainable agriculture.
5. Sustainable food and agriculture require responsible and effective governance mechanisms.

As the custodian for 2.4.1, which is the metric for SDG 2.4, FAO incorporated this work on sustainable agriculture into its 2017 Methodological Concept Note on Indicator 2.4.1 (FAO, 2017). In the note, FAO proposes 13 themes across the three dimensions of sustainability.

TABLE 5.1. THEMES PROPOSED BY FAO FOR EACH DIMENSION OF SUSTAINABILITY

SUSTAINABILITY DIMENSION	FAO-PROPOSED THEMES
Economic	Labour productivity
	Land productivity
	Farm income / Profitability
Environmental	Soil
	Water use
	Water quality
	Land-use change
	Biodiversity
	Energy use
	GHG emissions
Social	Decent work
	Household poverty
	Household / Farm resilience

Source: FAO, 2017.

Ceres2030 will work with FAO's dimensions of sustainability (to guide the choice of proxy indicators to track progress with SDG 2.4 in the model).

While indicator 2.4.1 is being finalized, some countries have already included indicators to track progress of SDG 2.4 in their voluntary national reports (VNRs). For example, some countries have proposed to use the share of land under organic farming as a proxy indicator.[1] This does not seem satisfactory to us, however, because while organic farming can promote some sustainable practices and reduce the use of emission-intensive inputs (such as pesticides, herbicides and chemical fertilizers), organic practices may perform less well on some other important indicators, such as crop yield. Furthermore, there is insufficient data on land in organic production at the global level.

[1] For example Germany, Belgium and Uganda proposed amount of land under organic production as the indicator to track progress with SDG 2.4 in their voluntary national report. Reports are available here: https://sustainabledevelopment.un.org/vnrs/

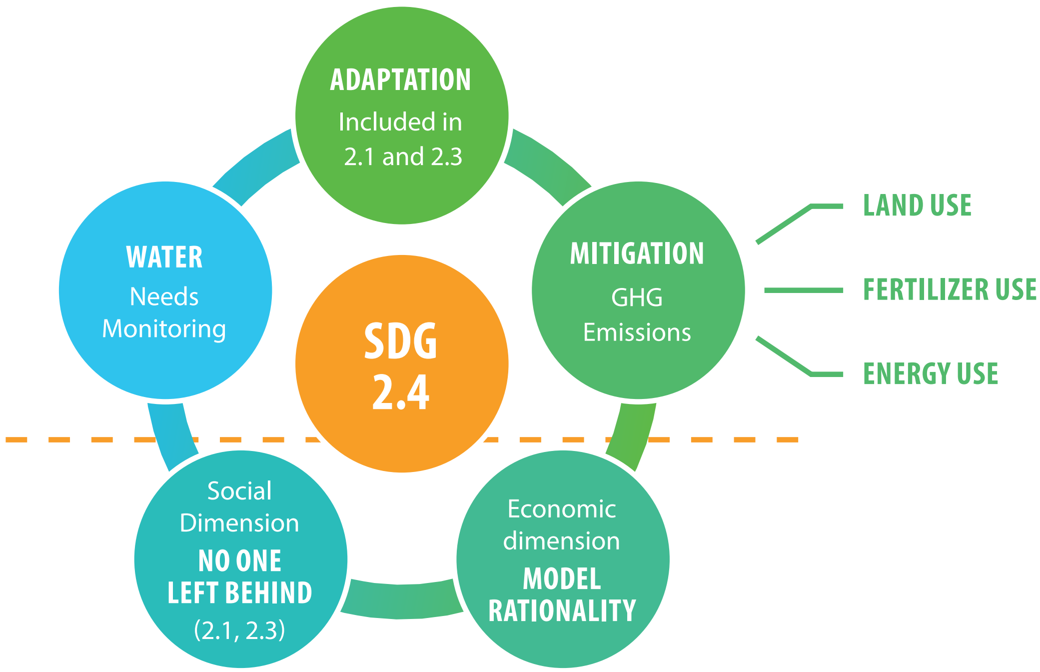
The themes in Table 5.1 above offer some limited guidance on how Ceres2030 might incorporate sustainability into its model, while awaiting the finalization of a formal indicator from FAO.

JUSTIFICATION FOR FOCUSING ON THE ENVIRONMENTAL DIMENSION OF SDG 2.4

The Ceres2030 model includes the three dimensions of agricultural sustainability as summarized in Figure 5.1. Economic sustainability is embedded into the model's core assumptions (so-called "model rationality"), which posits that economic agents take decisions by maximizing their profits and cannot operate at a loss, at least in the medium and long terms. The model guarantees positive rates of return of the various factors of production used in the farm sector in a competitive market. Specific metrics and targets for SDG 2.3 are included in our costing exercise using data from farm household productivity and small-scale producers' income. These are similar to the various "farm income / profitability" indicators emphasized by FAO's dimensions of sustainability in Table 5.1. Farm productivity is guaranteed in the model by producing products at the market rate.

"Labour productivity" and "Land productivity" are in the model but are not used as performance indicators. In this context, economic sustainability is ensured as long as the various subsidies received by farmers are included in the computation as additional income or as an input that raises factors of production. Finally, because our analytical framework does not allow for additional spending through increased governmental borrowing, the model results are compatible with the long-term economic sustainability of the public budget as well.

FIGURE 5.1. SUSTAINABILITY IN CERES2030 COSTING EXERCISE



Social sustainability, while a vital dimension of sustainability for both SDG 2 and the larger sustainable development agenda, is not fully captured in the model since it goes beyond economic variables and concepts. For instance, while wages are defined by market conditions and farm wages should remain competitive with the rest of the economy, we could not include specifications for principles such as "decent" work. Still, through SDG sub-targets 2.1 and 2.3, the model does include two elements that are necessary, albeit insufficient, for overall social sustainability: reducing the prevalence of undernourishment, which the model uses to incorporate SDG 2.1, and increasing small-scale producer incomes, which the model uses to incorporate SDG 2.3. Neither of these targets aligns exactly with the FAO dimensions of sustainability presented in Table 5.1, but both overlap significantly with "Household Poverty" and "Household / Farm Resilience." Because we monitor household-level income, the change in poverty rate at the international and national levels can then also be monitored in the model.

This technical note and the specific indicators for SDG2.4 in the costing exercise are therefore focused on the environmental dimensions of sustainability (upper part of Figure 5.1) as this is the dimension that was not tackled in the previous project[2] and needs to be explored. We are interested in addressing simultaneously:

- The mitigation dimension (limiting environmental damage) and
- The adaptation dimension (increasing farmer resilience to adverse environmental conditions).

Ceres2030 recognizes that achieving the goals of ending hunger and doubling small-scale producers' productivity and incomes will have a significant adverse environmental cost. Both these goals require the expansion of food production, and the agriculture sector is a leading source of environmental pressure, for example accounting for a quarter of anthropogenic greenhouse gas emissions (IPCC, 2014). More recently, the IPCC has warned that the development and expansion of the agricultural sector has a large part to play in the "rapid, far-reaching, and unprecedented changes" that are needed to avoid "long-lasting or irreversible changes" to the global climate (World Meteorological Organization, 2018).

Therefore, the primary reason for adding an environmental dimension in the model is to minimize the environmental footprint of achieving SDG 2 and maximize the use of environmentally friendly interventions. Furthermore, by using the most effective and targeted interventions, Ceres2030 aims to ensure the cost implications are achievable and realistic.

Similarly, unsustainable farm practices can lead to long-term effects on soil health, water availability and in turn threaten agricultural productivity and farmers' livelihoods—which are also threatened by climate change (Porter et al., 2014). While the upfront cost to invest in environmentally sustainable solutions may be higher, the long-term costs of unsustainable practices are potentially even greater.

MEASUREMENT FOR SDG 2.4 IN THE MODEL

DEFINITION OF SDG2.4 INDICATORS

In order to operationalize SDG 2.4, Ceres2030 focuses on the core externality issues and the missing markets for two natural resources: carbon and water. Indeed, these resources are extensively used and produced in agriculture but in most cases, they are not priced at all. Agriculture is responsible for 25 per cent of global annual emissions of GHG (UNFCCC) and uses 70 per cent of the world's fresh water (WDI, World Bank, 2018) while representing only 7 per cent of global GDP (WDI, World Bank, 2018). This leads to a market equilibrium that is far from the social optimum. Overuse of these resources will also lead to negative feedback that reduces agricultural productivity and farmer income in the long run. For example, excess GHG emissions will accelerate climate change, which may further stress fresh water

[2] Summary of the previous costing assessment is presented in Laborde et al. (2016), *Ending Hunger: What Would It Cost?*

availability. Furthermore, the two proposed indicators for inclusion in the model (GHG emissions and water use) are standard measurements in the current literature on food system sustainability (Springmann et al., 2018) and planetary boundaries (Poore & Nemecek, 2018). These two indicators also address a bias in measurement of actual productivity gains in agriculture, and they should be included in the measurement of sustainable agricultural productivity (Laborde & Piñeiro, 2018).

LIMITATIONS OF OUR APPROACH

Before discussing the strategy to integrate environmental sustainability, it is useful to mention the limits of this approach. First, the coverage of indicators remains a simplification of the complex environmental sustainability challenges. Biodiversity, for example—a critical dimension of environmental sustainability—is not integrated into the model, although the land-use change in the model could be a proxy for some biodiversity dimensions. Nutrient constraints (such as phosphates and phosphorous) and the overall issue of soil health, are also not integrated in the model, even though they are critical environmental issues in the current farming system.

The second limitation is the scale of analysis. While for other SDG targets Ceres2030 uses microeconomic data on household and farm performance for economic variables, we analyze environmental sustainability at a country level. For GHG emissions this is not a problem, and can even favour the outcome by allowing small-scale producers to increase fertilizer and energy use, while requiring larger farms to bear the cost of adjustment. For water use, the issue is slightly more problematic since water constraints can operate at a sub-national level. For this reason, we do not treat GHG and water indicators in the same way in the model.

The other dimensions of environmental sustainability discussed above cannot be properly integrated in the model because they vary significantly by sub-national region, and to understand the problem requires sub-national geographical information systems (GIS) data, which is beyond the scope and resources of the project. How to generate meaningful measurement indicators at the national level in the context of the spatial dimension of externalities is discussed in Fuglie et al. (2016), for instance.

GHG EMISSIONS

Tracking emissions in agriculture requires measuring emissions intensity of output for each activity in each country. Here, we focus on consolidated GHG emissions, expressed as CO_2 equivalent[3], as a key environmental indicator.

An excellent summary of the emissions associated with agriculture, forestry and land use is provided by Tubiello et al. (2013), with additional detailed estimates by country and mode of emission provided in FAOSTAT (www.faostat.org). The data suggests that the emissions associated with enteric fermentation[4] and agricultural soils[5] are the most important sources of emissions from agriculture. Figure 5.2a shows the contributions of the three main components of agricultural emissions to total emissions. This figure shows both the steady growth in agricultural emissions over the period, and the increase in the importance of emissions associated with agricultural soil management relative to other sources of emissions.

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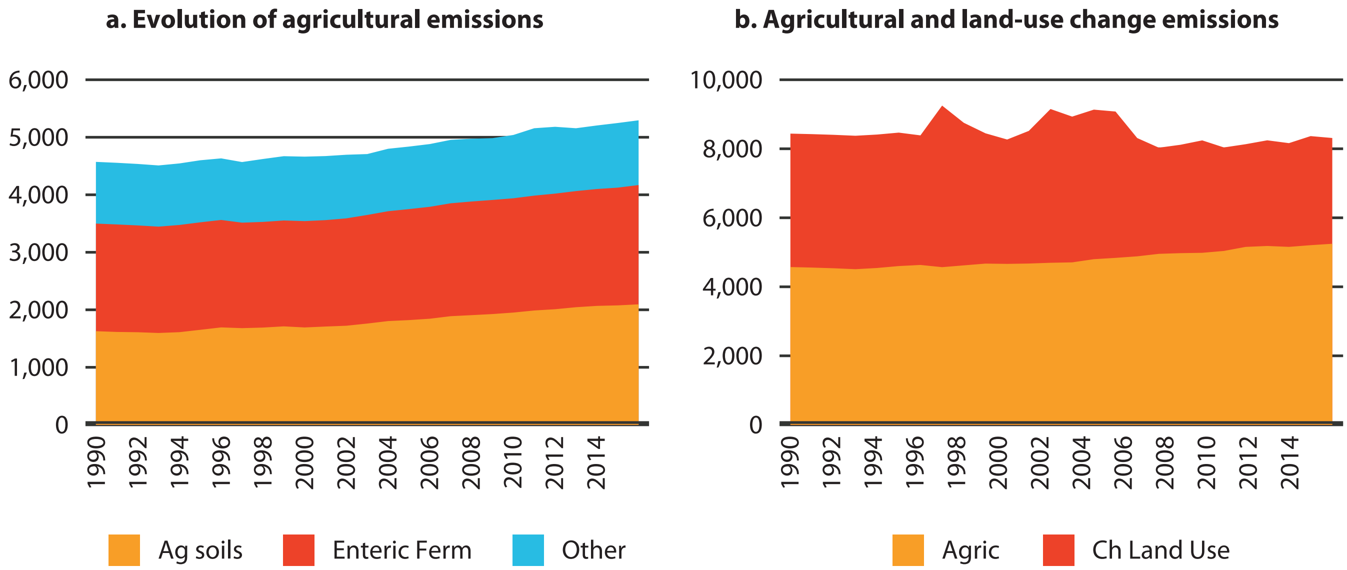
[3] Carbon dioxide equivalent is a measure used to compare the emissions from various greenhouse gases based upon their global warming potential (OECD, 2001).

[4] Particularly associated with emissions arising from ruminant digestive processes.

[5] Including emissions from crop residues, manure applied to soils, manure left on pasture, cultivated organic soils, and synthetic fertilizers.

FIGURE 5.2. AGRICULTURAL AND LAND-USE EMISSIONS (MILLION METRIC TONS OF CO_2 EQUIVALENT)



Source: FAO, n.d.

In previous decades, emissions from net deforestation were greater than those directly from agriculture in years such as 1995 and 2000. Since 2000, emissions from net deforestation have fallen. From 2005 to 2010 emissions from net deforestation were only around three-quarters of emissions from agriculture. Nonetheless, deforestation remains an important issue in tropical areas.

This structure of emissions suggests that the impact of land-use change on emissions, due for example to agricultural expansion, is likely to be very important. Figure 5.2.b illustrates the importance of emissions associated with agriculture and those associated with net land-use change. The figure reveals the substantial importance of emissions associated with land-use change relative to agriculture. It also shows the increasing importance of agricultural emissions relative to land-use change over the period since 1990. While land-use change emissions have been declining relative to agricultural emissions, they still accounted for 37 per cent of total agriculture and land-use change emissions in 2015. It is important to capture the drivers of emissions for agriculture and net land-use change separately because both are important to positive environmental outcomes, and they are affected differently by the two critical processes in the agricultural system: extensive and intensive land expansion.

The emissions intensity of each activity in each region for the baseline will be estimated in a manner consistent with the estimates at the country level in FAOSTAT category "Emissions - Agriculture: Agricultural Total," (FAO, n.d.) for the farm activities, and the International Energy Agency (IEA) for non- farm sectors. By crop and livestock sector, we break down the emissions measured at national level (indicators similar to those displayed in Figure 5.2) on subcategories:

- Land-use emissions:
    - ij Changes in land cover
    - ij Soil emissions
- Production emissions at the farm level
    - ij Fertilizer use
    - ij Fossil fuel-based energy use
    - ij Enteric fermentation
- Transportation and processing

While some of these estimates—such as those for rice cultivation—are closely linked to specific commodities or activities. Others—such as those associated with the use of synthetic fertilizers—are not directly attributable to identified agricultural activities in the existing dataset. A key step in constructing the necessary database is identifying the links between the aggregate emissions data and the data on commodities considered in the model. Importantly, with this level of detail on emission drivers in the farm sector we can use the heterogeneity among producers in their use of fertilizer and energy to distinguish between the different GHG footprints of smallholders and larger firms.

Building the link between an activity (at the country level) and an emission coefficient generates a matrix that allows us to combine data on emissions with the model outputs, to quantify changes in emissions, as the production and mix of inputs changes in the model in order to reach the goal. Therefore, we multiply this matrix coefficient with the model's appropriate variables (production and input uses). While all interventions will lead to changes in relative prices and production patterns, some interventions will also lead to changes in the value of the emissions coefficients.

Beyond the GHG indicators (total and per unit of output), we also use two additional metrics for measuring the evolution of the farm system: energy (Kcal) per unit of output, and tonnes of fertilizer per unit of outputs. The unit of output is expressed in constant dollars and in Kcal contained in the food system. These two metrics help to show the evolution of the efficiency of the system to achieve SDG 2.1 (Kcal consumption per household) and SDG 2.3 (farm income). We focus on GHG emissions instead of the other indicators as the overall constraint on the system because tonnes of CO_2 equivalent is additive across the different sources of emissions and environmental issues considered here, making it a useful proxy for overall environmental well-being.

The methodology for assessing land-use change impacts will be based on the methodology developed by Laborde (Laborde, 2011) focused on the assessment of EU biofuel policy using simplified land-use modelling with a country-specific land-use transition matrix (see Laborde, 2011 for more detail). Working with this methodology, the model will generate total change in land use (for pasture, cropland and each individual crops but also by type of producers). The net changes (amount of hectare) in agricultural land use is then allocated per land cover type. The transition matrix defines these changes.

We use two different matrices to allocate agricultural land expansion, and agricultural land contraction. Compared to Laborde (2011), we use fixed shares for two reasons. First, our household data does not guarantee a proper representativeness of the sample at the level of the agroecological zone. Even so, if this can be implemented in the future, the data availability limits the analysis at the national level for both farm technologies and land-use changes. Second, the use of a transition matrix makes it easy to incorporate feedback from national experts, changes in regulation (e.g., protected areas, conditionalities attached to investment) by limiting expansions in some cover types. This flexibility is seen as a strong argument in favour of using fully endogenous modelling options, since land-use changes are heavily driven by regulation and not by the changes in relative prices, which are the core drivers in our model. Finally, the modelers compute land-use emissions using the hectare changes in each land cover, positive or negative, combined with CO_2 stock coefficient per hectare, on the country level, based on Laborde (2011) and consistent with United Nations Framework on Climate Change (UNFCC) guidelines.[6]

Past and future trajectories of these indicators are available on our online platform: https://public.tableau.com/profile/laborde6680#!/vizhome/CERES2030TrackingSDG2_4/EmissionsPerI

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[6] See for example: https://unfccc.int/files/national_reports/annex_i_natcom_/application/pdf/non-annex_i_mrv_handbook.pdf

WATER USE

The approach we rely on for water use is very similar. We start with a matrix of water requirement coefficients (blue, green and grey) by agricultural products from Hoekstra & Chapagain (2006). Since these coefficients have been calibrated for a different base year, we use the FAOSTAT Water balance sheet to rescale these coefficients homogenously to reproduce country-level figures. We assume a homogenous technology at the benchmark meaning that water use by unit of output is the same for all producers in a given country. When running simulations, we use the change in the volume of outputs, combined with the unitary water use coefficients to compute the new total water requirement of the agricultural sector at the country level. As before, some interventions beyond changing the scale of production, and the product mix, may change the water intensity coefficients. By default, the mix between blue, green and grey water will not be changed, except when a specifically targeted intervention deliberately changes the ratio.

CONSTRAINTS AND SDG 2 TARGETS

A separate technical paper will focus on scenario development and how we set constraints on the level of GHG emissions from agriculture in each country. Here, though, it is important to underline that we are using a positive approach rather than a normative one. When available, we use the 2015 Paris Agreement National Determined Contributions (NDCs)[7] to define the target for greenhouse gas reductions that each country has committed itself to. In our view, this approach fits best with the SDGs, as they are seen as inspirational goals and should be based on individual country ownership instead of defining exogenous targets imposed on them from the outside. Since no such target exists for water use, we monitor and compute water use indicators in our costing exercise, but we do not impose constraints and thresholds ex ante.

COMPARISON WITH FAO'S DRAFTED APPROACH

As shown in Table 5.1, FAO proposes seven themes within the environment dimension of SDG 2.4— Soil, Water Use, Water Quality, Land-Use Change, Biodiversity, Energy Use and GHG Emissions—each of which will have a sub-indicator. FAO is developing these sub-indicators and will combine them in some way to create the 2.4.1 indicator.

The methodology for 2.4.1 is not fully complete; nor is the data for the proposed methodology available. Where the methodology is complete and available to be used, it will be integrated into the model. Where gaps remain, Ceres2030 will build its own metrics from globally available data for 2.4.1 to provide stakeholders with timely and actionable results.

While all seven dimensions above are important metrics of sustainability, they have a great deal of overlap. For example, we might consider that "Land-Use Change" and "Energy Use" are important primarily because of their implications for climate change through the released GHG emissions. Thus, our model will use just one metric—GHG emissions—to incorporate the three FAO themes of "Land-Use Change," "Energy Use" and "GHG Emissions." The Ceres2030 GHG emissions metric will include breakout metrics for land, fertilizer and energy use.

FAO suggests "Conservation area as a proportion of total farm area" as the sub-indicator for biodiversity protection. The Ceres2030 model will project forested land and wetlands as a proportion of total land use, which is an indicator that is affected by agricultural expansion, in the simulations. It is not included as a constraint because effective conservation of biodiversity is more a function of what land is conserved than how much is conserved (quality rather than quantity). This policy question is important but less relevant to the cost estimations and spending allocation recommendations to meet SDG 2, which is the primary objective of the Ceres2030 modeling exercise.

"Water Use" is an important aspect of environmental sustainability, as pressure on water resources around the globe is rising, and this trend is expected to continue (UNWWAP, 2015). It also addresses an environmental component that is

[7] https://unfccc.int/process/the-paris-agreement/nationally-determined-contributions/ndc-registry

distinct from GHG reduction in the short term, justifying its explicit inclusion in the Ceres2030 model. The model will project and monitor the use for green, blue and grey water use in agricultural production.

"Water Quality" and its sub-indicator, "Fertilizer and pesticide use in excess," are difficult to measure, not least because of the importance of local concentrations. The definition of excess can vary based on the crop, soil and fertilization timing for any specific plot of land. This implies that imputing the average fertilizer use per hectare by crop from country-level data, as our model will do, can only provide a general idea of whether pesticide use is "in excess." However, cost and spending allocation recommendations should not be highly sensitive to the accomplishment of water quality goals, since excessive use can occur mostly because of specific interventions (fertilizer subsidies, extension programs about fertilizer use).

"Soil" and its sub-indicators, "Rates of Soil Erosion (tonnes/ha)" and "Soil organic carbon (tonnes/ha)" will not be included in our model, due to the lack of global data. These indicators could be included in the future if the data were to become available.

Table 5.2 summarizes the Ceres2030 model's coverage of FAO's environmental themes for SDG 2.4.1. The themes are still under review by FAO. The Ceres2030 model includes some consideration of six of the seven themes; soil is the one excluded, due to the data limitations.

To conclude, Ceres2030 will focus on GHG emissions and constraints set in nationally determined contributions (NDCs) to UNFCCC and monitor water use in its simulations. These aspects are key because of their implications for the cost of achieving SDG 2.4 and because they are especially pressing topics.

TABLE 5.2. FAO-DEFINED SDG 2.4.1 ENVIRONMENTAL THEMES IN THE CERES2030 MODEL

FAO THEME	FAO-PROPOSED SUB-INDICATOR (DATA NOT YET AVAILABLE)	CERES2030 SUB-INDICATOR
Land-use change	Impact of agricultural expansion	**Land-Use Change contribution to greenhouse gas emissions**
Energy use	Final energy use / Farm volume of ag. Production (joules/ tonne)	**Energy use in agricultural production**
GHG emissions	GHG emissions (CO_2 eq.) / Farm output volume	**GHG emissions at the country level, compared to Nationally Determined Contributions from the Paris Agreement**
Biodiversity	Conservation area as a proportion of total farm area	**Forested and wetland land as a proportion of total land use**
Water use	Water abstraction for agriculture from surface and groundwater as a percentage of available water	**Green, blue and grey water use in agricultural production**
Water quality	Fertilizer and pesticide use in excess	**Fertilizer use per hectare by crop**
Soil	Rates of soil erosion (tonnes/ha) Soil organic carbon (tonnes/ha)	**Not included – global data not available**

Source: Based on United Nations Statistics Division, 2018.

INTEGRATION OF RESILIENCE IN THE MODEL

The FAO themes speak heavily to mitigation aspects of environmental sustainability but leave the question of resilience of food and agricultural systems untouched. SDG 2.4 does include explicit references to resilience and a potential adaptation agenda:

> By 2030, ensure sustainable food production systems and *implement resilient agricultural practices* that increase productivity and production, that help maintain ecosystems, *that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding, and other disasters* and that progressively improve land and soil quality (United Nations, 2018).

Resilience measures are important to SDG 2 because climate change is expected to harm agricultural productivity and will affect progress toward the ending of hunger. Climate predictions suggest that there will be impacts from climate change before 2030, with larger impacts expected after 2050 (Havlík et al., 2015). Indeed, the 2018 State of Food Security and Nutrition in the World report identifies climate variability and extremes as "among … the key drivers behind the recent uptick in global hunger, and one of the leading causes of severe food crises" (FAO, IFAD, UNICEF, WFP, & WHO, 2018). Climate change impacts can make it challenging to achieve the SDGs, a tension that is also stressed in the recent IPCC report (Roy et al., 2018). Action to mitigate and adapt to climate change will affect agricultural output and may require spending trade-offs among interventions (this is true across many SDGs).

Our model will use existing consensus on the effects of climate and other factors to predict yield from now through 2030. Due to the lagged effect of GHG emissions on climate, the feedback effects of GHG emissions changes are not included in the model, as they fall outside the period considered. Nevertheless, it will be possible to experiment with different climate change assumptions in the model to assess the effects of a set of indicators to measure resilience, as suggested in the literature (Bizikova et al., 2015; Bousquet et al., 2016). These different climate change assumptions could affect the relative importance of interventions to address climate change in the model depending on the levels of the resilience of the countries studied and will also change the estimated cost of achieving SDG 2.4. Indeed, some SDG 2.4-focused interventions, especially those focused on mitigation and adaptation to climate change, will support a virtuous circle of benefits, in which offsetting climate change will minimize the medium- to long-term agricultural productivity losses.

HOW CERES2030 "STANDARD" INTERVENTIONS ARE IMPACTING SDG2.4

Farm policies have potentially large impacts on environmental outcomes. At worst, subsidies may encourage production at high economic and environmental costs inside protected markets, while denying access to supplies from countries where production is more environmentally friendly. At best, support might encourage producers to move in a direction that is both environmentally and economically efficient. The environmental impact, on water and GHG emissions, is mainly driven by the direct impact on production through the following channels:

i. The scale of production (**How much** is produced)
ii. The pattern of agricultural goods produced (**What** is produced, the composition effect in the product space)
iii. The geographical pattern of production (**Where** goods are produced, the geographical composition effects: within and across countries)
iv. The technology involved in producing the goods (**How** goods are produced).

To summarize, the environmental impact of support to agriculture is both a question of scale (i, ii and iii in the list above), and of technology effects (iv). The total GHG emissions generated by an activity are dependent upon the level of output, and the emissions generated per unit of output. In general, interventions that lead to increased output increase emissions from the region affected by the intervention. This increase in emissions will reflect both the increase in output and the increase in the amount of resources per unit of output needed to achieve the higher level of output. Use of subsidies that are directly linked to higher production ("coupled support") will be particularly damaging for global emissions if emissions per unit of output are higher in the region using the intervention than in other regions. Use of subsidies that are not directly linked to production ("decoupled support") would, by contrast, transfer revenues to its recipients without substantially changing output levels, reducing both economic and environmental costs, and providing greater benefits to producers per unit of assistance provided. There is ample scope to implement interventions that encourage environmentally friendly changes in the technique used for production. Support that encourages the use of agricultural technologies that are designed to limit GHG emissions (such as zero-till production) may both increase output and reduce environmental impacts. Similarly, interventions that encourage reductions in the enteric emissions associated with ruminant animals could significantly reduce GHG emissions from agriculture.

Another important influence on environmental outcomes is the effect on land use of changes in agricultural policy. Agricultural incentives that induce land transfer from forestry to agricultural crops are likely to have particularly significant effects on GHG emissions (Laborde, 2011). At a global level, a technological advance that raises agricultural productivity may reduce the amount of land needed for agricultural production and may, in this way, reduce the environmental impact of agriculture. However, this mechanism occurs only under specific economic conditions for both supply and demand, and adverse effects can also take place (e.g., increased deforestation due to productivity gains, which is an example of the Jevons paradox[8]). Having proper quantification of these issues is particularly important for agriculture given the large share of emissions that come from deforestation and the major adverse impacts of soil degradation on yields and the capacity of soils to sequester greenhouse gases.

Overall, significant productivity gains, especially when not associated with more input uses, could significantly reduce total emissions (both land and production) per unit of output.

Standard Ceres2030 interventions are listed in Table 5.3, with their expected impacts on our indicators (Tier 1, see Technical Note 1.1.a). Beyond this list of interventions, we will consider new interventions targeting the SDG 2.4 outcomes. Tier 2 interventions are those with a strong focus on reduction of environmental impacts in coefficients related to water use, energy use, soil emissions or fossil fuel intensity of energy sources. Still, these interventions could have contrasted impacts, in particular when expanding consumption or production possibilities. In this case, the intensity effects could be lower than the extensive effects. For instance, rural electrification via solar panel, while reducing the carbon footprint of energy use in agriculture, can lead to overuse of limited water resources (Hartung & Pluschke, 2018).

Also, SDG 2.4 interventions with a strong resilience focus (climate smart agriculture) could offset the impact of climate change.

[8] Jevons paradox refers to efficiency improvement in the technical process of the use of a resource that ultimately defeats the original purpose through a higher overall use by society (Dumont et al., 2013). This effect and its explanation were first described in relation to the use of coal in England by the economist William Stanley Jevons at the end of the 19th century (Alcott, 2005)

TABLE 5.3 IMPACTS OF CERES2030 INTERVENTIONS ON ENVIRONMENTAL INDICATORS

#	INTERVENTION	IMPACT ON GHG EMISSIONS	IMPACT ON WATER USE
Category I: Social safety nets*			
1	Food subsidy	Increase due to increase in food consumption. Changes in relative prices can also change the food basket toward goods with higher or lower environmental impacts (e.g., animal products).	
Category II: Sustainable farm support			
2	Investment subsidy	Increase in production emission (extensive and intensive) effects Potential reduction in land use	Increase due to additional production (extensive effect)
3	Fertilizer subsidy		
4	Capital endowment		
5	Production subsidy	Increase due to extension of production	Increase due to extension of production
6	R&D National Agricultural Systems (NARS)	Increase due to extension of production Reduction of emission intensity	Increase due to extension of production
7	R&D CGIAR		
8	Extension Services		
Category III: Rural development			
9	Storage-Post Harvest losses	Reduction due to minimized losses of crops and decrease in crop production	
10	Rural Infrastructure: Irrigation	Increase due to extension of production	Increase due to extension of production and irrigation coverage
11	Rural Infrastructure: Roads	Increase due to extension of production	Increase due to extension of production

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Ceres2030
Sustainable Solutions to End Hunger

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Ceres2030 brings together three institutions who share a common vision: a world without hunger, where small-scale producers enjoy greater agricultural incomes and productivity, in a way that supports sustainable food systems. Our mission is to provide the donor community with a menu of policy options for directing their investments, backed by the best available evidence and economic models.

The partnership brings together Cornell University, the International Food Policy Research Institute (IFPRI) and the International Institute for Sustainable Development (IISD). Funding support comes from Germany's Federal Ministry of Economic Cooperation and Development (BMZ) and the Bill & Melinda Gates Foundation (BMGF).

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