INaRA: A Framework for Integrated National and Regional Assessments of Agricultural System Adaptation to Climate Change

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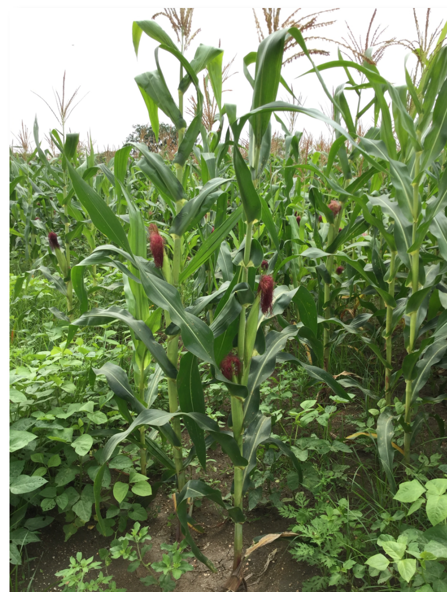

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A Framework for Integrated National and Regional Assessments of Agricultural System Adaptation to Climate Change

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This document describes the design and main elements envisaged for national model-based assessments of national adaptation plans (National Integrated Assessment, or NIA), implemented together with regional (sub-national) assessments of agricultural system risks, vulnerabilities, resilience and adaptations utilizing AgMIP Regional Integrated Assessment (RIA) methods. We describe the combined national and regional assessment as Integrated National and Regional Assessment (INaRA).

The first section provides an overview of the INaRA goals and approach. We then address INaRA design, including the linkage between model-based analysis and a country's National Adaptation Planning and related climate policy and other policy design and implementation. The remainder of this document provides additional details on the components of national assessments and the linkage to regional (sub-national) assessments of agricultural systems that use AgMIP's regional integrated assessment (RIA) methods.

Acronyms used in this report:

AgMIP	Agricultural Model Inter-comparison and Improvement Project
CMIP6	Coupled Model Intercomparison Project Phase 6
IFPRI	International Food Policy Research Institute
INaRA	Integrated National and Regional Assessment
NAP	National Adaptation Plan
NIA	National Integrated Assessment
NRDI	National-Regional Data Interface
RAP	Representative Agricultural Pathway
RCP	Representative Concentration Pathway
RIA	Regional (Sub-National) Integrated Assessment
SSP	Shared Socio-economic Pathway
UNFCCC	United Nations Framework Convention on Climate Change

INaRA Goals and Approach

The principal goals of INaRA are to:

- Analyze the country's agricultural sector performance under current and alternative strategies to implement its national adaptation plan (NAP), using stakeholder-defined performance indicators, national data and national impact assessment models;
- Complement and support regional integrated assessment (RIA) of agricultural system risks and adaptation at the regional (sub-national) level by regional teams of stakeholders and scientists.

A National Adaptation Plan (NAP) is a part of the ongoing process developed by the UNFCCC to identify medium- and long-term adaptation needs, and develop and implement strategies and programs to address those needs. For example, a NAP could establish the amount of funding earmarked for agricultural research on climate adaptation, and alternative strategies for implementation could establish priorities for particular regions and production systems in the country.

To achieve these two goals, INaRA begins with the identification of a set of scenarios defined over a stakeholder-defined planning horizon. Each of these scenarios is comprised of two main components: a strategy for national adaptation plan implementation; a future pathway comprised of projected future climate conditions (associated with Representative Concentration Pathways, or RCPs); and socio-economic conditions (represented by global Shared Socio-economic Pathways, SSPs, and national Representative Agricultural Pathways, RAPs).

INaRA uses quantitative modeling to evaluate the performance of the country's agricultural sector and main agricultural systems for each scenario using stakeholder-defined performance indicators for each scenario (Figure 1). These indicators can be measures of agricultural productivity, prices, food consumption, food stability and other environmental and social indicators discussed in this report.

Using this approach, model simulations allow national stakeholders to evaluate alternative adaptation strategies, compare the range of plausible outcomes achievable with alternative adaptation strategies. The modeling methods also provide stakeholders with a way to evaluate the uncertainty associated future climate and socio-economic pathways, as well as uncertainties associated with the models used

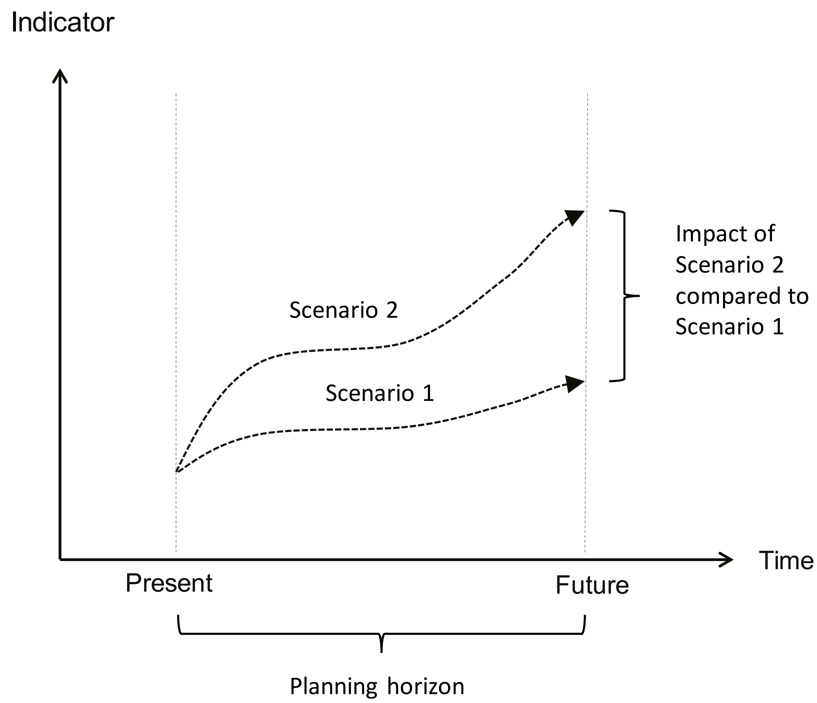

Figure 1. INaRA scenario design to assess alternative adaptation strategies. Each scenario is composed of an adaptation strategy and projected future climate projections (SSP-RCPs) and socio-economic pathways (RAPs). For example, Scenario 1 could be a "baseline" or "business as usual" scenario without adaptation and Scenario 2 could be a scenario with a specified National Adaptation Plan and a set of system-level adaptations.

INaRA Modeling: Design and Implementation

INaRA modeling is designed to project the future value of aggregate economic indicators (e.g., aggregate commodity productivity, production, consumption and prices), environmental indicators (e.g., greenhouse gas emissions, water, and air quality, aggregate fertilizer and chemical use), and social indicators (e.g., national per capita income and poverty rates, per capita food consumption and food security). The differences in the data and models at these scales create major challenges to INaRA implementation. For example, national analysis typically operates on an annual time step. In contrast, regional integrated assessments (RIAs) may operate on seasonal time steps suitable to farm systems and households and corresponding indicators such as farm income, crop production and yields, regional poverty, household food security. These time steps typically do not begin or end with the annual calendar. The entire agricultural sector of a country is comprised of many components from farm to national scales that are jointly and dynamically determined in space and time. However, due to the data and analytical challenges, it is not currently possible to simulate these large, complex systems at both regional and national scales as one large model.

The solution proposed here is to develop a process that involves both formal modeling at national and regional scales, as well as informal, expert-judgment processes to make linkages and ensure logical consistency between national and regional modeling. A spreadsheet tool, the "National-Regional Data Interface" (NRDI), provides a common set of identifiers and other information that enables coordination between scales (Figure 2).

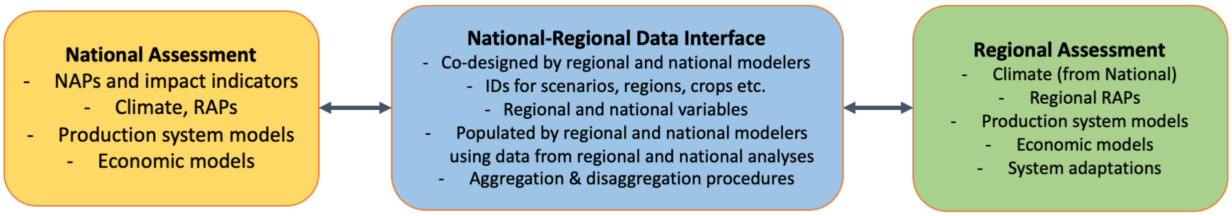

Figure 2. Linkage of national and regional (sub-national) modeling through the National-Regional Data Interface (NRDI)

INaRA aims to support a country's ongoing NAP process as well as related policy decision making. Critical elements of INaRA are therefore coordination with national institutions leading the NAP and committing resources to support the INaRA activities. Given the available resources, national and regional modeling teams need to be established and participate in the design of INaRA in collaboration with the NAP team and other institutions involved in related policy decision making.

The first step in INaRA is to make decisions about key components jointly with national stakeholders:

- national impact indicators to be included (quantitative and qualitative)
- national modeling team components and membership (climate, production systems, economics, environmental, and social component)
- regions & systems to be included, and members of regional teams to implement RIAs
- a work plan for national assessment and coordination with regional teams.

The national assessment is designed and implemented in coordination with a set of RIAs for each major region and agricultural system in the country. RIAs provide region- and system-specific analysis to support the national-level policy design and implementation. A key feature of an RIA is the regional and agricultural system-level specificity needed to design and evaluate farm-level adaptations effectively. The AgMIP *Guide for Regional Integrated Assessments: Handbook of Methods and Procedures, Version 7.0.* http://agmip.org) describes methods for the regional assessments. In many cases, the RIA methods will need to be adapted to fit the data availability, resource constraints and priorities of a specific country's INaRA.

INaRA implementation will involve a set of iterative steps to coordinate national and regional analyses. The fact that, in reality, national and regional outcomes are jointly determined in a complex, dynamic process creates a methodological "chicken-and-egg" problem. For example, national analysis requires estimates of regional system productivity; however, regional productivity depends on nationally or internationally determined prices. The national and regional teams will need to establish a set of initial assumptions to populate the NRDI, and then establish a schedule to coordinate national and regional analyses and iteratively update the NRDI.

INaRA Components and Linkages to Global and Regional Modeling

Figure 3 illustrates the main components and linkages in INaRA. The next section discusses indicators that can be used to assess performance at the national level. The subsequent sections provide anticipated protocols for each of the national modeling components.

National Indicators

A variety of economic, environmental and social indicators can be used, depending on data availability and the available models. Here we group indicators according to the three broad areas of sustainable development – economic, environmental and social. There are a number of systems of normative goals and indicators that are now being used. For example, progress towards the seventeen UN Sustainable Development Goals is measured with multiple indicators for each goal, and many of the SDGs are directly related to agriculture. The CGIAR has identified five specific impact areas: nutrition and food security; poverty reduction, livelihoods and jobs; gender equality, youth and social inclusion; climate adaptation and greenhouse gas reduction; environmental health and biodiversity.

An important limitation of model-based integrated assessment is the "bias" towards quantifiable indicators, with the consequence of often ignoring some environmental or social impacts that are difficult to quantify with available models. For example, Antle and Valdivia (2020) discuss the models that are available to quantify indicators related to the CGIAR's five impact areas, as well as the relevant impacts that are not currently quantifiable with models. To address this limitation, they recommend a stakeholder-based process that first identifies relevant outcomes and impacts in each of the three dimensions of sustainability, and then addresses how relevant indicators – both quantitative and qualitative – can be incorporated into the analysis. We envisage a similar approach for the identification of national and regional integrated assessment indicators. A process similar to the development of Representative Agricultural Pathways (RAPs) is appropriate for this purpose.

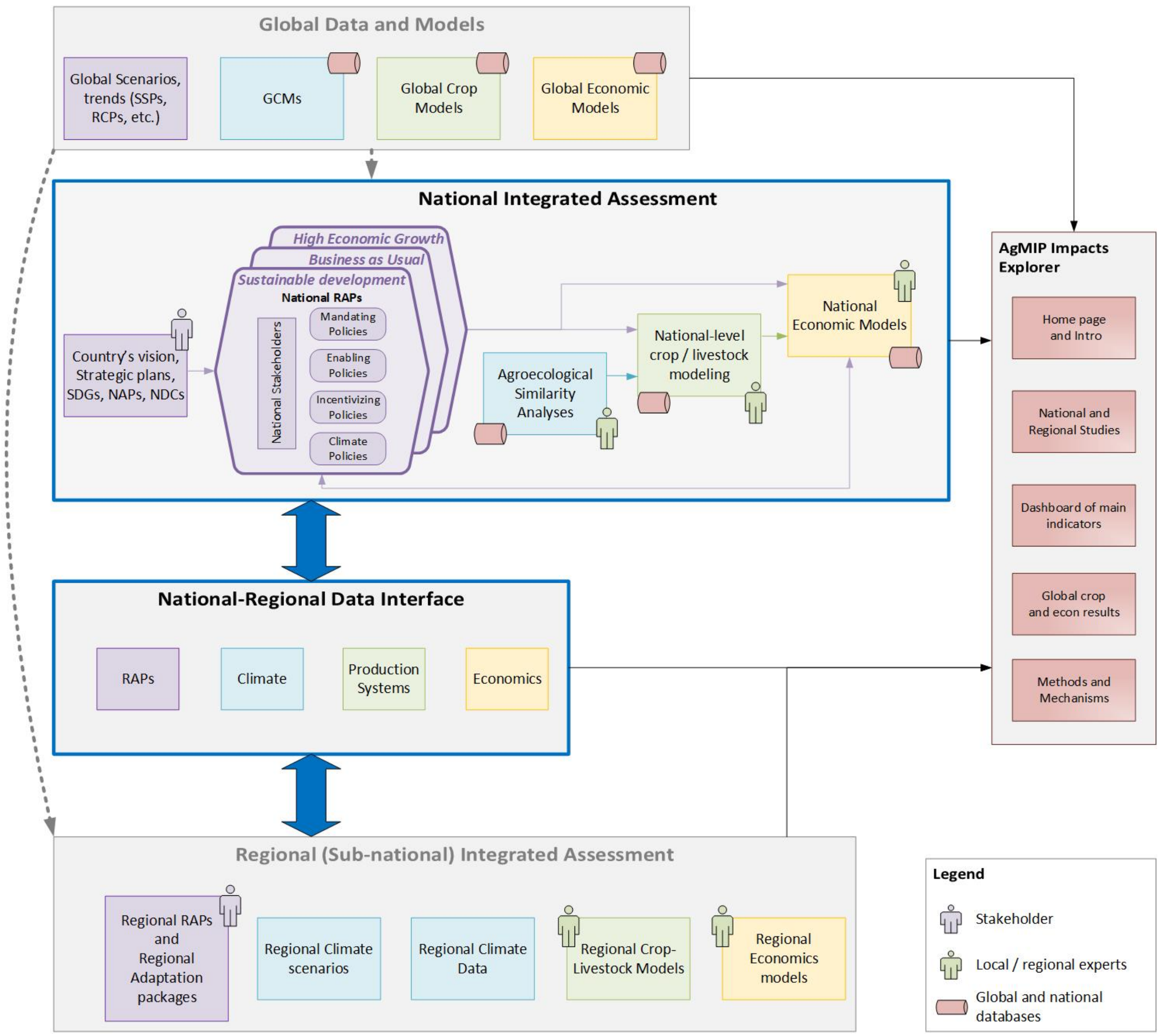

Figure 3. INaRA Components and Linkages.

An important aspect of the RIA method is to quantify vulnerability of farm households to climate impacts and the effects of adapting farm household systems to climate change. In addition to income vulnerability, food security indicators and indicators related to assets such as livestock can be used. This is an area where national models are very limited in their capability to represent impact, thus alternative methods should be explored. For example, review and synthesis of existing regional vulnerability studies, together with RIA vulnerability assessment, could be used to identify vulnerable regions, systems and populations. This information could be combined with national modeling to translate and disaggregate national outcomes into implications for vulnerable regions and groups.

Economic Indicators:

- Commodity productivity (i.e., crop yields)
- Commodity area and production
- Local commodity consumption
- Agricultural commodity prices
- Agricultural commodity trade (imports, exports)

Environmental Indicators

- Land area cultivated by conventional or conservation tillage
- Soil erosion
- Agricultural chemical use: organic and inorganic fertilizers, pesticides
- Energy use
- Irrigation and water use
- Net greenhouse gas emissions (carbon dioxide, nitrous oxide, methane)

Social Indicators

- Income distribution (poverty rates, urban and rural)
- Food security (various objective and subjective indicators; national, urban, rural)
- Gender equity (education, labor participation, asset ownership, income)
- Health (life expectancy, urban and rural, by gender and age)

Toward Protocols for INaRA Components

Climate

Climate information for INaRA activities will be drawn from observational datasets and climate models with the goal of providing daily climate series that may be used to drive production models (crops and livestock). Climate analysis will follow a common set of protocols to ensure that each regional and national element may be connected with the others under illustrative and coherent future storylines. Configuration of production models will prioritize local observations and national meteorological networks, with coarser global products available to fill in gaps. Projections will be rooted in the latest CMIP6 climate projections across low (SSP1-2.6), moderate (SSP2-4.5) and high emissions (SSP3-7.0) scenarios, with a subset of models selected to represent the global distribution of equilibrium climate sensitivities.

Practicality limits evaluation of all combinations of climate models, SSP-RCPs, RAPs, crop models and adaptation packages, and thus INaRA activities will develop an ensemble of bias-adjusted scenarios for analysis. The primary subset of climate scenarios will be selected to highlight particular storylines of regional change, including moderate and high local warming rates, shifts toward wetter or drier conditions, and shifts in locally-important climate features such as rainy season onset dates (building from Ruane and

McDermid, 2017). The resulting model subset will also be related back to the full CMIP6 set of models in order to understand the likelihood of each storyline in the broader CMIP6 ensemble.

Historical climate and future climate scenarios will cover each country from 1980-2100 with 0.5˚ x 0.5˚ resolution and will be bias-adjusted to better represent observed average and extreme conditions (e.g., from NASA NEX). The scenario set will also be further compared against finer resolution historical observations and dynamically-downscaled climate projections (e.g., from the COordinated Regional Downscaling Experiment, CORDEX) to identify residual differences in local features and regions where local topography, land cover or coastlines modify the rates of climate change. These comparisons will further contextualize results and provide additional detail about regional patterns of impact.

Representative Agricultural Pathways: Global, National and Sub-National

The process of developing RAPs across scales builds on the RAPs development protocols used in AgMIP's Regional Integrated Assessments of climate change and adaptation (Antle et al., 2015; Valdivia et al., 2021). The goal is to develop national-level RAPs that describe plausible futures aligned with the countries' visions of sustainable development and climate change policies. Regional (sub-national) RAPs incorporate policy and technological interventions set at national level and provide with storylines and quantifiable parameters to be used as inputs to crop-livestock and economic models. Additional RAPs representing different plausible futures can be developed to assess impacts of climate change on farming systems under different future conditions. The key to this process is ensuring the consistency across the scales.

Scales. The RAPs development approach is a nested approach that links drivers and outcomes across scales:

Global: Higher level pathways are used to define external drivers that may influence some of the National -and sub national- drivers. In AgMIP's scenario development Shared Socio-economic Pathways (SSPs) are used to describe the future global socio-economic conditions, including price and productivity projections

National: At this level, national RAPs include policies and agricultural planning that focus on the entire agricultural sector and cover the whole country. Drivers at national level might be influenced by external factors, like those in the SSPs or other aspects like international trade, international agreements, and commitments. National drivers in turn, influence the Sub-National drivers.

Sub-National: At Sub-National level, we can define RAPs at two sub-levels. In cases where geographical division is important for the implementation of the national policies (e.g., State, Province, etc), then RAPs can be developed for these levels. The regional RAPs contain most of the State/Province level narratives, but are focused to the specific farming system to be analyzed (e.g., Crop-livestock system in Nkayi, Zimbabwe). The quantification of key drivers of these RAPs are used to parameterize crop, livestock and regional and national economics models.

Linking Regional RAPs to National RAPs*.* Development of a Regional RAP follow these overall steps:

1. The process starts by characterizing the current state of the farming system, including the current policy conditions.
2. Using narratives of future global socio-economic scenarios (SSPs), information about current and proposed national policies (in some cases projected into the future) and with input from stakeholders and the team of scientists and experts, a description of "future states" of the agricultural farming system are created (overall RAP narratives).
3. With the definition of the future scenarios, an iterative process is carried out to identify the key drivers of change (policy/institutional, economic, technology and bio-physical) that would support the RAP narrative (i.e., the future conditions of the agricultural system).
4. The regional RAP is finalized by defining qualitative and quantitative changes for key drivers. The process starts over to develop additional regional RAPs.

In the AgMIP-CLARE project, regional and national RAPs were developed following the process described in Figure 4. Linkage of national-level RAPs to regional RAPs follows these steps:

1. Characterize the current state of the agricultural sector in the country. Use of available information to define the structure of the government, organizations and identify key stakeholders (those who can be part of the process during the project, and the high-level stakeholders to whom the results will be presented).
2. Identify and describe the long-term vision of the country using Sustainable Development plans, Strategic Vision, National Adaption Plans, etc. Focus on the agricultural sector, but also be inclusive of policies and plans from other sectors that may have an effect on the agricultural sector (e.g. energy, health, education, etc).
    - The strategic vision or sustainable development plans usually have key pillars around which policies and interventions are built to achieve goals regarding environmental protection, achieve economic efficiency, agricultural sustainable development, energy production, social equity, food security, etc. In many cases a set of indicators are associated with these plans.
    - The goal is to develop contrasting RAPs that highlight particular decision contexts, thus, after finalizing the RAPs that represent the future state under the strategic visions or country's sustainable development plans, a similar iterative process to create additional RAPs is started.

3. Using the above information, and the defined global SSPs, the team, invited experts and stakeholders define the plausible future states of the agricultural sector, or the 'overall RAP narratives'.
4. The next step is an iterative process that starts with identifying the key drivers of change (use the strategic vision, sustainable development plans, etc to determine these drivers). National and agricultural policies define the policy/institutional and socio-economic conditions of the National RAPs. The different types of policies help to contextualize RAPs, define the key variables that may have a direct or indirect effect on the sub-national level drivers. Examples of drivers and specific variables are shown in Table 1.
    - Once identified the key drivers, a process similar to the regional RAPs is followed: Using the DevRAP matrix, for each driver, a direction and magnitude of change is proposed. Storylines to justify these changes are elaborated and levels of agreement are assessed.
    - As in the regional RAPs, variables are assigned to team members, experts and stakeholders to research about the plausible trends following the overall narrative. All documents, studies, papers, etc. used need to be documented and stored on a shared Google Drive folder.
    - The team will revise the storylines as they are crafted to make sure there is internal consistency across the drivers.
    - The output of the iterative process is a full draft of National RAPs.
    - The next step is to revise the regional RAPs to make sure there is consistency across scales.
    - The team will meet and review and discuss the full Regional and National RAPs.
5. New RAPs can then be developed by following the same iterative process with the main goal of identifying those drivers that would lead to an alternative future state (e.g. a less sustainable development oriented RAP).
6. The quantification of the revised regional RAPs will be input to the TOA-MD model and complement the data needed to implement the RIA. Outputs from this process will be included in the NIA

Mapping National Policies to RAPs. In order to help with the process of identifying the key drivers from National policies and link them to the RAP process, we use a Policy Matrix template created in Excel. This matrix lists all drivers and specific variables that are key to describe the national and agricultural policies in the context of the country's strategic vision, sustainable development plans and climate change plans (NAPs, NDCs, etc). The matrix also allows to identify how they may influence regional RAPs and how they are influenced by global scenarios (SSPs).

The policy matrix helps to categorize the type of policies as: 1. Enabling; 2. Incentivizing; 3. Mandatory; 4. climate policies; and 5. guidelines or programs implemented or planned by the government.

The team uses this matrix to evaluate importance of each policy and how these can be incorporated and quantified in the different RAPs. In addition, climate policies are used to develop assumptions about the implementation of future climate policies (Shared Policy Assumptions, SPA).

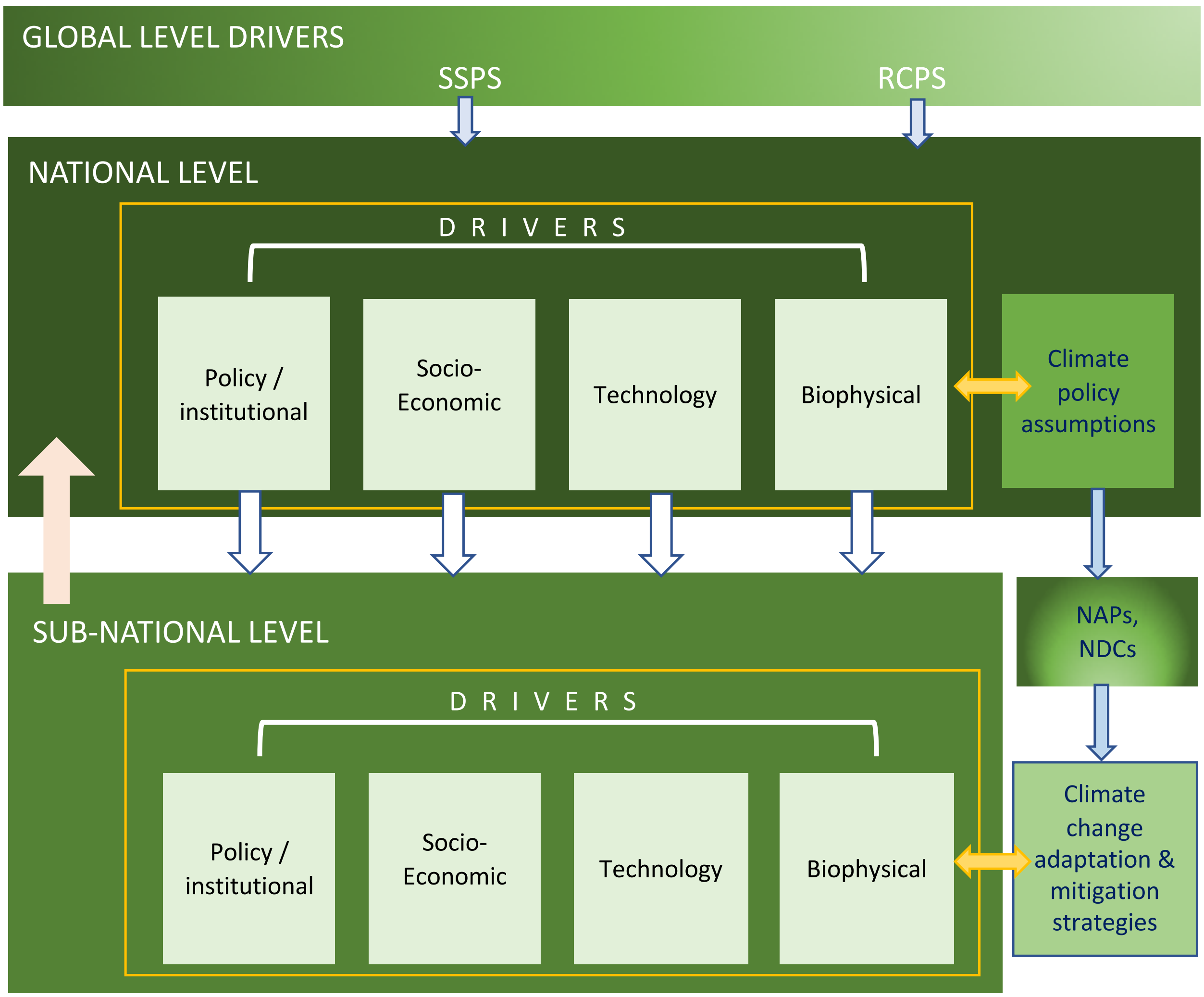

Figure 4. Linking RAPs across scales: Global-National-Regional

Table 1. Example of drivers and variables for nationall RAPs (PES = payment for ecosystem services, GMO = genetically modified organism)

Driver	Variables
Regional Development	Context: Regional; West Africa (ECOWAS)
Economic growth	GDP, Agricultural GDP share
Population	Population growth, rural to urban migration
Literacy	Education investment, programs
Healthcare	Investment on healthcare, programs
Land Use	Expansion/contraction, change to new crops (as policy, incentives, land protection, etc)
Energy	Fossil fuel use, policies
Agricultural policies	Subsidies, taxes, quotas, policies on specific commodities, PES
Food production policies	GMOs, organic, etc
Environmental policy	Conservation policies, etc
Climate change policies	NAPs, NDCs strategies
Trade policies	Tariffs, imports/exports
Technological change	R&D investment
Water	Water use and allocation regulations, bio-physical conditions
Biodiversity	Regulations on biodiversity, incentives, PES
Level of governance	National and Sub-National
Sub-national development	Rural development policies
Social policy	Education, equity, gender
Markets	Investment, infrastructure, price controls/ceiling

Crop Production Models

Crop Simulation Models can be used to simulate the spatial distribution of crop yield and production across the national domain using GIS-based data layers for soil properties, weather, management, and cropping areas. The resolution of the data inputs may vary based on data availability, but typically a spatial grid size of 5 arc-minutes (about 11 km) is sufficient to characterize the spatial variability of crop yields. Average or typical values of modeling inputs are used for simulation of yields in each pixel or grid cell.

Inputs to gridded crop model simulations include:

- Weather data products as described above in the "Climate" section. These products are based on satellite data and are generally at a courser resolution than many other crop production inputs.
- Soil properties. Several digital soil properties products are available, with quality and spatial resolution dependent on location.
- Crop management data, including cultivar and crop selection, fertilizer application rates, and cropping calendars are available in digital, gridded formats. These data products also vary widely with location and crop. In all cases, the products should be supplemented with local knowledge of the cropping systems being modeled.
- Cropping area masks supply information about the location and intensity of cropped areas for different crop and management types.

Estimates of the spatial distribution of cropping area are combined with simulated yields to compute crop production in each pixel. Production values can then be aggregated to national and other administrative boundaries.

Calibration and evaluation of crop production is done at the country or Administrative Level 1, depending on availability of production statistics.

Yield from gridded national crop simulations can be compared to yields simulated for regional integrated assessments, although the results are not expected to be exact due to the different types of input data. Input data for RIA crop model simulations are obtained from specific farms, whereas the national gridded simulations are based on large-scale representative values for the input data. However, regional trends for climate change and socio-economic scenarios are expected to be similar for both methodologies.

Many minor crops and livestock activities cannot be modeled with the current models. In the RIAs, these gaps are filled with data from literature reviews and expert judgment. For national analysis, similar procedures will be required, and the results will be incorporated into the NRDI so that consistent values are used for both national and regional analyses.

Crop models can be used to predict many variables related to crop growth and development, environmental variables, GHG emissions, resource requirements, and the potential for soil carbon sequestration. The variables of interest in RIA and NIAs are crop yield and production for the most important commodity crops in the country. Crop models can also be used to produce information on resource requirements for irrigation and fertilizer; environmental variables such as nitrogen leaching or soil organic matter depletion; and the shifting of crop timing due to climate change.

Crop yield and production data to be included in the IE includes:

1. National crop production variation maps (i.e., raster images, typically on approximately 11 km resolution),
2. Production difference maps for selected scenarios,
3. Tabulation of crop production by administrative level 1, and
4. Comparison of anticipated crop yield variation between scenarios using box and whisker diagrams

Livestock models also are required for both regional and national analysis. Some national models have explicit livestock components including meat and dairy production. Regional analyses also need to incorporate livestock. The complexity of livestock production systems poses significant challenges at both regional and national scales. This is an important area where collaboration among regional and national researchers will be required to populate the NIA so that consistent assumptions are used at both scales.

Environmental Models

A number of environmental models are available for use at the national level, depending on the capabilities of the modeling team and data availability. For example, the IFPRI IMPACT model includes a water model that simulates water availability for agriculture. Some agricultural system models include environmental components, such as soil carbon or nitrous oxide emissions. However, due to the site-specific character of most environmental processes and outcomes, environmental modeling may be best implemented at the regional (sub-national) scale.

Agroecological Similarity Analysis

Analysis of climate, soil, agricultural management, social, and remote sensing geoinformation provides further information about common agroecological conditions and challenges within the country. Regional maps show the extent of specific evaluated systems in order to identify the broader areas where specific adaptation packages are viable. Analysis also provides insights about regions that are already experiencing challenges that will be more widespread in the future, and points toward adaptations that are currently in practice to overcome those emerging risks.

National Economic Model

Most national economic models that are appropriate for use in INaRA simulate national-level agricultural commodity markets (demand and supply), and their linkage to international markets through trade. When being used for INaRA, they are used to simulate the effects of climate adaptations and related policies on national outcomes such as agricultural production, consumption, prices and trade.

Most agricultural models are referred to as "partial equilibrium," because they represent the determination of agricultural commodity prices, production and consumption, taking other drivers such as income as given by the other parts of the national economy. In contrast, general equilibrium models simulate the functioning all commodities, factors, and institutions within the economy, and in which adjustments to relative prices ensure that all markets clear, but do so at a higher level of aggregation and thus provide less detail on individual agricultural commodities. Partial and general equilibrium models have different strengths and weaknesses, but complement each other when analyzing long-run trends under climate change.

A nationally focused partial equilibrium model, such as IFPRI's IMPACT-SIMM model, presents a tractable, and practical tool for examining detailed country scenarios.

Linkages to global economic models: Data requirements for the national economic model can be extensive. Baseline data, such as world prices, population, income, supply and demand indicators, trade, irrigation, elasticities, and productivity growth, can reasonably be linked to larger, global models with consistent units, and commodity and geographic coverage. In this way, the national model can be initialized to the results of a global economic model, ahead of any policy-adjusted scenarios.

Linkages to national RAPs: Policy choices used in scenarios in the national (or regional) RAPs process can be different to baseline values, and meaningfully influence outcomes in the economic model. These include assumptions of economic and population growth, which can influence the level of household demand in scenarios. Also, policy choices such as tariffs and subsidies can exert pressure on consumer and producer prices. These should be incorporated into the economic model to ensure that results correctly capture the effects of those assumptions/policy actions. As far as possible, tariff and subsidy assumptions should be made at the commodity level, with guidance as to how the policy change is implemented over time.

The results from the national economic model can be passed back to the national RAPs to examine potential effects of different policy choices on variables such as domestic prices, production, planted areas, and yields, among others. These outputs can be used to inform a refined design of adaptation packages and contribute to the iterative process with the RIAs.

Linkages to crop simulation models: The national economic model can draw policy-adjusted crop yield or area results from crop simulation models, as scenario inputs. These would impact supply-side variables such as production. Data from crop simulation models, which are often done at a detailed spatial level, should harmonise with the geographic units available in the economic model.

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