Chapter 5

Representative Agricultural Pathways and Scenarios for Regional Integrated Assessment of Climate Change Impacts, Vulnerability, and Adaptation

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Introduction

The global change research community has recognized that new pathway and scenario concepts are needed to implement impact and vulnerability assessment where precise prediction is not possible, and also that these scenarios need to be logically consistent across local, regional, and global scales (Moss *et al.*, 2008, 2010). For global climate models, representative concentration pathways (RCPs) have been developed that provide a range of time-series of atmospheric greenhouse-gas concentrations into the future (Moss *et al.*, 2008, 2010; van Vuuren *et al.*, 2012a). For impact and vulnerability assessment, new socio-economic pathway and scenario concepts have also been developed (Kriegler, 2012; van Vuuren *et al.*, 2012b), with leadership from the Integrated Assessment Modeling Consortium (IAMC).

> The new scenarios will provide quantitative and qualitative narrative descriptions of socioeconomic reference conditions that underlie challenges to mitigation and adaptation, and combine those with projections of future emissions and climate change, and with mitigation and adaptation policies. They will provide a framework for underpinning, creating, and comparing sectoral and regional narratives.
>
> (Carter *et al.*, 2012).

This chapter presents concepts and methods for development of regional representative agricultural pathways (RAPs) and scenarios that can be used for agricultural model intercomparison, improvement, and impact assessment in a manner consistent with the new global pathways and scenarios.[1] The development of agriculture-specific pathways and scenarios is motivated by the need for a protocol-based approach to climate impact, vulnerability, and adaptation assessment. Until now, the various global and regional models used for agricultural-impact assessment have been implemented with individualized scenarios using various data and model structures, often without transparent documentation, public availability, and consistency across disciplines. These practices have reduced the credibility of assessments, and also hampered the advancement of the science through model intercomparison, improvement, and synthesis of model results across studies (see, e.g., Easterling *et al.*, 2007; Nelson *et al.*, 2014; Rosenzweig *et al.*, 2013a). The recognition of the need for better coordination among the agricultural modeling community, including the development of standard reference scenarios with adequate agriculture-specific detail, led to the creation of the Agricultural Model Intercomparison and Improvement Project (AgMIP) in 2010. The development of RAPs is one of the "cross-cutting themes" in AgMIP's work plan, and has been the subject of ongoing work by AgMIP since its creation (Antle *et al.*, 2014b; Rosenzweig *et al.*, 2013b).

[1] In the following section we provide definitions that clarify the difference between pathways and scenarios as we use them in this chapter.

The first section of this chapter presents the concepts underlying AgMIP's development of RAPs at global, regional, and local scales. The second section provides a detailed description of the methods used to develop regional RAPs by the AgMIP regional teams. The third section presents a summary of the regional teams' RAPs and their implications for climate impact assessment and adaptation, then discusses lessons learned from the experiences of the regional teams in implementing the RAP development process. The final section summarizes and draws implications for future regional RAPs development and use.

Box 1. Acronyms.

AgMIP	Agricultural Model Intercomparison and Improvement Project
BAU	Business-as-usual
CCAFS	Climate Change, Agriculture and Food Security Research Program of the CGIAR
CGIAR	Consultative Group on International Agricultural Research
CMIP	Coupled Model Intercomparison Project
CSM	Cropping system model
ESM	Earth system model
GCM	Global climate model
GDP	Gross domestic product
IAM	Integrated assessment model
IAMC	Integrated Assessment Modeling Consortium
RCM	Regional climate model
RCP	Representative concentration pathway
SAS	Story and simulation approach to scenario analysis
SRES	Special Report on Emissions Scenarios
SSP	Shared socio-economic pathway
TOA-MD	Tradeoff Analysis Model for Multi-dimensional Impact Assessment
RAP	Representative agricultural pathway

The Conceptual Framework for RAP Development

In this section we first describe briefly the new global pathway and scenario concepts that have been developed for use with global integrated assessment models. Then we present AgMIP's global and regional integrated assessment framework and discuss the central role that RAPs play in it. Finally, we summarize some of the conceptual issues that arise in constructing sector-specific and region-specific pathways that link to global pathways.

Pathway architecture: Representative concentration pathways (RCPs) and shared socio-economic pathways (SSPs)

The parallel development of new greenhouse gas concentration and socio-economic pathways is intended to ameliorate inconsistencies at the aggregate, global scale. Figure 1 presents a scenario matrix showing how RCPs and SSPs proposed by Kriegler *et al.* (2012) could be combined. As this matrix implies, RCPs and SSPs are designed to be independent dimensions, to reflect the fact that a particular concentration's trajectory could correspond to various socio-economic conditions that cause and are caused by greenhouse-gas emissions and the resulting climate change. Thus, various socio-economic scenarios could be designed to represent, say, future worlds with either low or high emissions combined with various levels of economic activity and types of mitigation and adaptation capabilities and policies. As Fig. 1 also indicates by the shading, some combinations of RCPs and SSPs may not be plausible (say, very low emissions with very high economic growth).

Socio-economic pathways are multi-dimensional concepts that embody economic and social development, adaptation and mitigation capability, and non-climate policy dimensions. To incorporate climate policy dimensions, researchers have proposed "Shared Climate Policy Assumptions" as another set of dimensions of an impact assessment (Kriegler *et al.*, 2014). As with the Special Report on Emissions Scenarios (SRES) scenarios (Nakicenovic *et al.*, 2000), a key feature of SSPs is a set of corresponding narratives that contain the rationale for the features of the pathway. Researchers can use these narratives to interpret the pathway logic; a feature

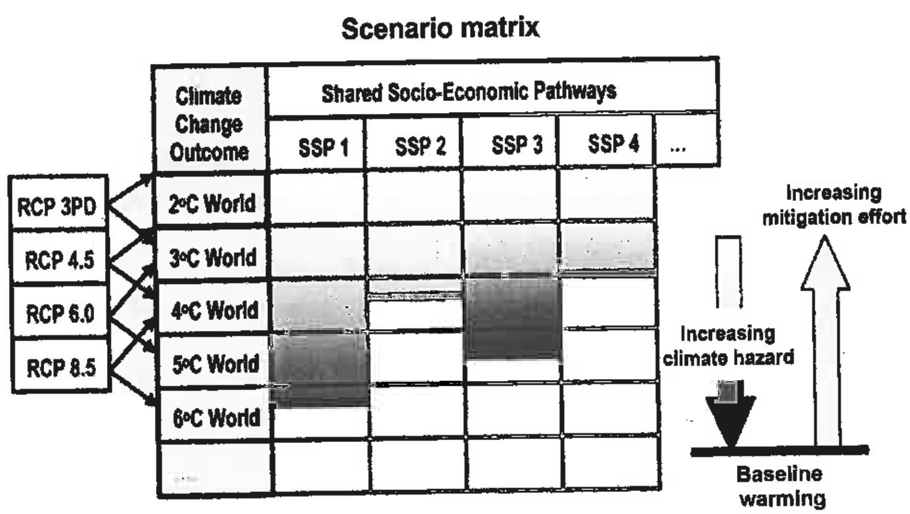

Fig. 1. Scenario matrix with SSPs on the horizontal axis and RCPs on the vertical axis (Kriegler *et al.*, 2012). Note that the SSPs listed here are hypothetical and therefore do not correspond with those in Fig. 2. Reprinted from Kregler *et al.* (2012) with permission from Elsevier.

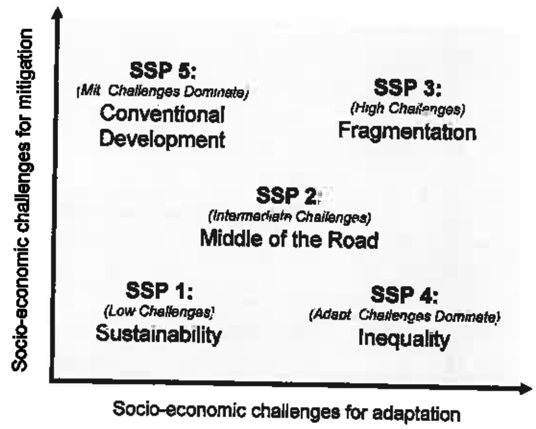

Fig. 2. Five-pathway SSP matrix (O'Neill *et al.*, 2012).

important for the "sharing" or using the pathways for different types of research, and also for developing sector- and region-specific versions such as the agricultural pathways we discuss in the next section.

For communication with the research community and stakeholders, it is useful to be able to represent these multi-dimensional concepts in a two-dimensional form. Figure 2 shows an SSP matrix that defines five possible SSPs in terms of different degrees of "challenges to adaptation" (or ability to deal with climate change that has already occurred) and "challenges to mitigation" (or ability to restrain the extent to which climate change will occur) as well as other features of socio-economic development. These five SSPs have become the basis for quantification of key drivers, such as population, economic growth, urbanization, education, and land use (International Institute for Applied Systems Analysis, 2012). Narratives associated with these SSPs can be found in O'Neill *et al.* (2012).

Two key features of the new global pathway developments should be emphasized. First, it is assumed that socio-economic pathways can be defined in a way that is largely independent of the emissions pathway and associated changes in climate that occur — this is the logical basis for the "matrix architecture" of the RCPs and SSPs presented in Fig. 1. Second, the characterization of SSPs is fundamentally "climate-centric" by being defined in relation to climate adaptation and mitigation challenges.

The role of RAPs in AgMIP's global and regional integrated assessment framework

Building on AgMIP's integrated assessment framework (Rosenzweig *et al.*, 2013b), Fig. 3 provides a stylized representation of the linkages between global climate

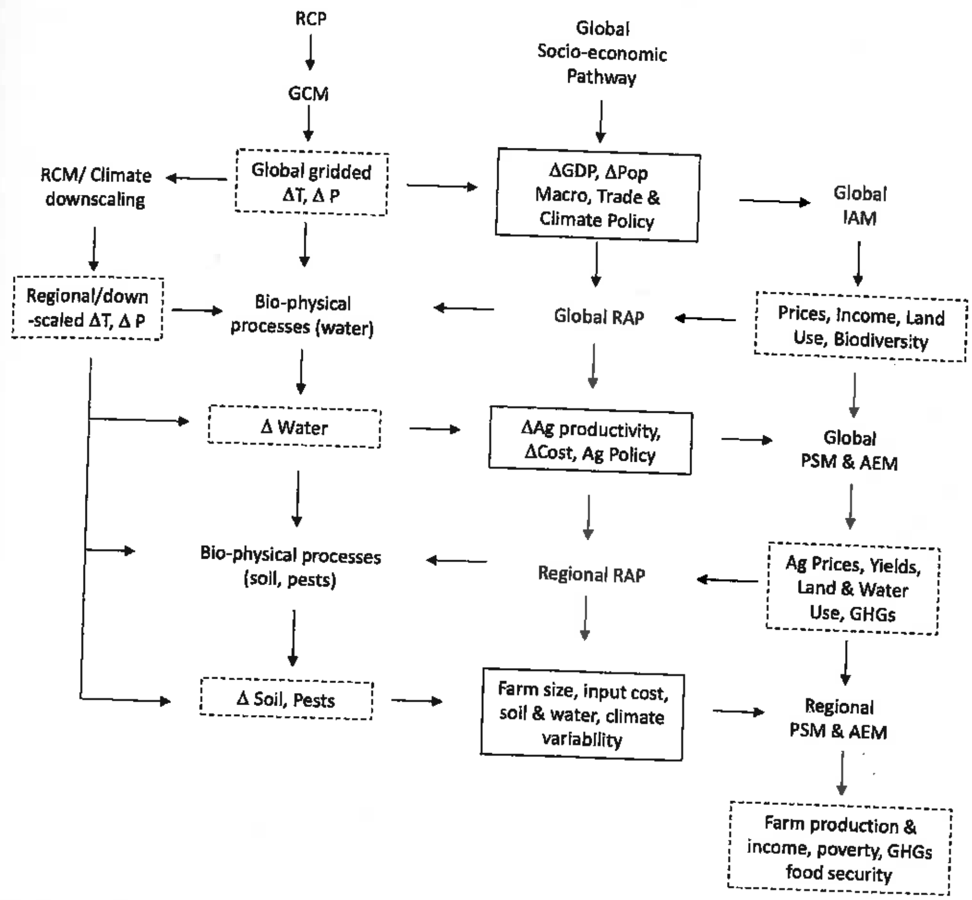

Fig. 3. An elaboration of AgMIP's global and regional integrated assessment modeling framework. Note: RCP = representative concentration pathway; GCM = global climate model; RCM = regional climate model; T = temperature, P = precipitation; IAM = integrated assessment model; RAP = representative agricultural pathway; PSM = biophysical production system model; AEM = agricultural economic model; solid boxes indicate variables determined by global socio-economic pathways and RAPs, dashed boxes indicate model outputs. Moving from top to bottom represents different geographic scales (global to regional to local), and the three columns of the figure represent biophysical models and data (left-hand column), biophysical and socio-economic pathways (center), and impact models (right-hand column).

models and data, global integrated assessment models (IAMs), and global and regional agricultural models used for climate impact, adaptation, mitigation, and vulnerability assessment. This figure shows the hierarchical structure of the relationships between global and regional data and models, and between aggregate and disaggregate ("regional") data and models. Dashed boxes represent model outputs at each level, which serve as inputs for lower-level (sectoral or regional) models. However, these higher-level outputs are not sufficient to implement the lower-level models, so they are augmented by variables derived from pathways developed for each level of analysis. Moving from top to bottom, Fig. 3 represents different geographic scales (global to regional to local), and the three columns of the figure represent biophysical models and data (left-hand column), biophysical and socio-economic pathways (center), and impact models (right-hand column).

The top of the figure represents the main components of global integrated assessments. RCPs and GCMs combine to generate climate outputs on a global gridded basis. These climate outputs are combined with inputs from global socio-economic pathways, such as projected rates of economic growth and population, macro-economic and trade policy parameters, and climate policy assumptions, which serve as inputs into global IAMs. These global IAMs typically generate global and multi-country or country economic outcomes such as production, prices, and incomes; some models also simulate certain biological or physical outcomes such as changes in land use or land cover. Depending on the type of model, these outcomes may be generated for multi-country regions, by country, or subregions of a country.

Agricultural assessment models operate at both global and regional scales. At the global level, biophysical production system models can be simulated on a gridded basis (Havlík *et al.*, 2014; Rosenzweig *et al.*, 2013a) or on a point basis and then aggregated (Ewert *et al.*, 2011). In some cases, these models are used to generate inputs for partial- or general-equilibrium agricultural economic models (Nelson *et al.*, 2010, 2014). These models may use outputs from the global IAMs (e.g., prices of energy, income), or may use some of the same drivers from the global socio-economic pathways that global IAMs use, such as gross domestic product (GDP) and population growth rates. However, both agricultural production system models (PSMs; including crop and livestock simulation models) and agricultural economic models (AEMs), require additional inputs that are not provided by global IAMs. These variables include technology or productivity growth rates for individual outputs (crops, livestock); and, in more detail, food-specific demand elasticities; and agriculture-specific inputs as labor, machinery, seed, fertilizers, irrigation water, and fuels. In addition, agriculture-specific policy parameters may be needed, e.g., for domestic output or input taxes or subsidies, and parameters for trade policy (e.g., tariffs). Thus, global RAPs are needed that are consistent with global socio-economic pathways but that provide the additional sector-specific detail needed to implement biophysical PSMs and AEMs.

The biophysical component of the assessment framework beyond the GCM outputs involves several components. First, regional climate models or downscaling of gridded GCM outputs to higher spatial and temporal resolution is needed to serve as inputs to global gridded PSMs and regional gridded or point-based PSMs.

In addition, the framework may include a water component (e.g., the SWAT (Soil and Water Assessment Tool) model), or a soil erosion component (e.g., using the EPIC (Erosion Productivity Impact Calculator) model). These models may be implemented on a global basis, as is done for water supply-demand in the IMPACT AEM model (Rosegrant *et al.*, 2012), or may be done on a gridded basis as is done with EPIC in the GLOBIOM AEM model (Havlík *et al.*, 2011). Similar model linkages may be done on a national or subnational model, as with FASOM (Forest and Agricultural Sector Optimization Model) for the US (Ohrel *et al.*, 2010) or the TOA-ME (Tradeoff Analysis Model for Multi-dimensional Market Equilibrium) model (Valdivia *et al.*, 2012). At both the global and regional scales, these models may involve drivers such as details of land use or water use that are not available from higher-level models, and thus need to be specified as part of RAPs.

Global AEMs generate projections of globally consistent market equilibrium commodity-specific prices, yields, and acreages that can be used as drivers for regional AEMs which do not solve for global equilibria. There are various types of regional AEMs, ranging from representative farm optimization models, regional optimization models (e.g., Merel and Howitt 2014), regional technology adoption and impact assessment models such as TOA-MD (Antle 2011; Antle and Valdivia, 2011; Antle *et al.*, 2014a), regional land-use models (Wu *et al.*, 2004), and national partial-equilibrium economic models such as FASOM (Ohrel *et al.*, 2010) or the SEAMLESS-IF system developed for the EU region (van Ittersum *et al.*, 2008). These models may utilize variables from global models as drivers, notably, prices, productivity, and land use.

At the regional level, some AEMs continue to be formulated on a commodity basis, but some models represent production of crops and livestock as integrated systems. Some models also incorporate a household production component, as well as non-agricultural income-generating activities. Generally, models do not exist to project this level of detail for model inputs and thus inputs must be addressed using RAPs. Essential details typically include input cost or use by type of production activity, including livestock; some models also require data on farm and household characteristics such as farm size and number of people in the household, as well as non-agricultural income. Some models require detailed use on farm labor, including household members and hired workers. Greater detail on policy parameters, such as domestic output, input, and environmental subsidies may be needed, as well as parameters related to climate mitigation policy. When these models are linked to PSMs, details on management inputs are also required for those models.

A major limitation of most PSMs is that they are not capable of simulating the effects of pests and diseases on crops or livestock. Therefore, an important topic for transdisciplinary collaboration is to address the potential of new pests and diseases to impact the production system being modeled, and how these pests and diseases may be managed. In the meantime, pest and diseases can be addressed using RAPs.

Implications for RAP design

The framework in Fig. 3 has a number of important implications for the design of RAPs (Antle *et al.*, 2014b).

Is the matrix architecture useful for RAPs?

The integrated assessment framework presented above raises questions about the usefulness of the "matrix" architecture proposed for the development of RCPs and SSPs at the global scale. As Fig. 3 implies, the issues of spatial and temporal scale, and associated issues of aggregation and disaggregation, must be addressed when pathways and scenarios are linked across scales. The effect of this linkage across scales is to blur the distinction between "drivers" and "outcomes" that underlies the pathway concept. For example, consider the role that prices play on the global, regional, and local scales. The price of a commodity like wheat is determined by global markets, and thus is an outcome of global models, whereas it plays the role of an input or driver on the regional or local scale. Thus, because the global models determine prices as functions of specific RCPs and SSPs, if prices are considered to be part of a RAP then the RAP cannot be independent of the RCP or SSP. Similar issues arise with policies, e.g., climate mitigation policy, which would be expected to interact dynamically with emissions and thus with the rate of climate change. Likewise, elements of RAPs could include biological processes such as the spread of pests and diseases that are determined in part by climate.

A response to this criticism could be that RAPs are meant to be elements of the future world that can be defined independently of climate, and that climate-specific elements should be part of "scenarios" that are based on a RAP, and which potentially include adaptation packages designed to respond to specific climate change projections while still being consistent with the broader pathway. However, if the many key features of the future world are climate-related, then one can question how useful it is to define "pathways" separately from "scenarios". As Fig. 1 shows, the farther down ones goes from global to regional and local scale, the more climate-dependent elements there are likely to be in an analysis, and thus the less useful is the matrix architecture.

Should RAPs be climate-centric?

Agricultural-impact models depend strongly on both biophysical and socio-economic drivers, and historically agriculture has undergone rapid technological change that has induced large changes in the economic organization of the agricultural sector. As a result, previous studies have consistently shown that trends in non-climate factors, such as population growth and technological change, are likely to have a large influence on agricultural production and related human well-being (Nelson *et al.*, 2010; Parry *et al.*, 2004). Accordingly, the framework proposed by Antle *et al.* (2014b) for the development of RAPs (elaborated below) is based on the characterization of key biophysical and socio-economic drivers. This approach contrasts with the climate-centric global pathway and scenario framework described above that emphasizes "challenges to adaptation" and "challenges to mitigation" as key dimensions that guide global pathway development for use in global IAMs.

Transdisciplinary pathways: Combining biophysical and socio-economic dimensions

One of the key motivations for the new pathways concepts has been the growing recognition of a need for a more integrative or parallel process to develop projections of emissions and socio-economic development. AgMIP's experience in developing RAPs shows that this process must be not only parallel but *trans-disciplinary*, which means that it needs to involve an integrative process of collaboration among disciplines to produce outcomes that transcend what can be achieved by individual disciplines, or by simple passing of data or other information from one disciplinary researcher or group to another.

The need for a transdisciplinary approach is motivated, firstly, by the fact that agricultural pathways need to address key biophysical dimensions important to agriculture, as discussed above. Moreover, a transdisciplinary approach is needed to ensure logical consistency between model components on a given spatial and temporal scale, as well as across scales (see Fig. 4). As the discussion of Fig. 3 showed, this need for a trans-disciplinary approach increases as we move from the highly aggregated level at which global pathways and scenarios are developed and used in models, to the disaggregated sectoral, regional, and local levels at which analysis of climate impact and adaptation also needs to be carried out.

Figure 5 portrays five possible RAPs corresponding to combinations of low and high economic development and more or less sustainable biophysical conditions. In contrast to Figs. 1 and 2, the axes are defined in positive terms. RAP 1 is the case of adverse synergies resulting in low outcomes in both dimensions, which might occur if persistently high population growth led to both poverty and environmental degradation as is true in some counties today. RAP 3 is described as the opposite case of win–win synergies in both dimensions and thus represents sustainable high growth, e.g., a shift to soil- and water-conserving tillage systems that also achieve high

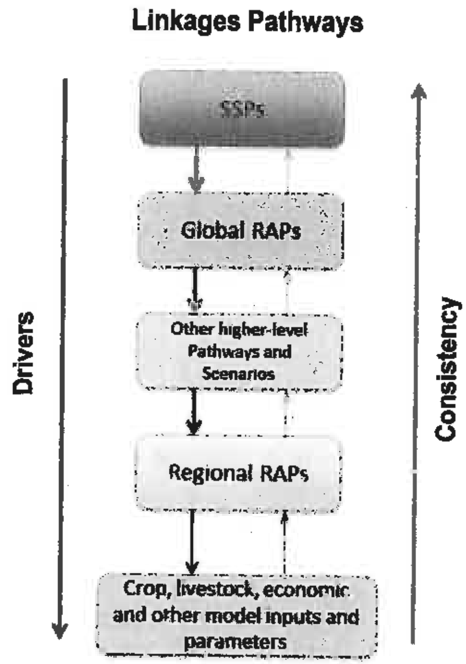

Fig. 4. Linkages from global and regional pathways and scenarios for disaggregation (downscaling) and development of model-specific scenarios.

productivity. RAPs 4 and 5 represent cases of strong tradeoffs between economic and environmental outcomes. RAP 4 could correspond to a case of policies that achieve environmental protection by severely restricting economic activity; RAP 5 might correspond to the continuation of present trends in some industrialized countries where productivity growth continues at a high level by continuing to exploit natural resources in an unsustainable manner. This latter example illustrates that the time-horizon of a RAP is a crucial element, since RAP 5 might be a plausible option in the near term but not feasible in the longer run if the high rate of economic growth depends on an unsustainable rate of depletion of natural resources such as soil, water, or biodiversity. RAP 2 represents a middle-ground balance of economic and sustainability indicators.

As we noted above, a basic question about this type of RAP design is whether they can be defined independently of greenhouse-gas concentration scenarios (RCPs). In our view, this may be a useful way to think about global RAPs, although even at this level, defining elements such as water resources independently of climate scenarios seems questionable unless it is clearly defined as only the demand element of a more complex water-resource-management system. As the research focus moves to regional and local scales, we find that this decoupling is less useful.

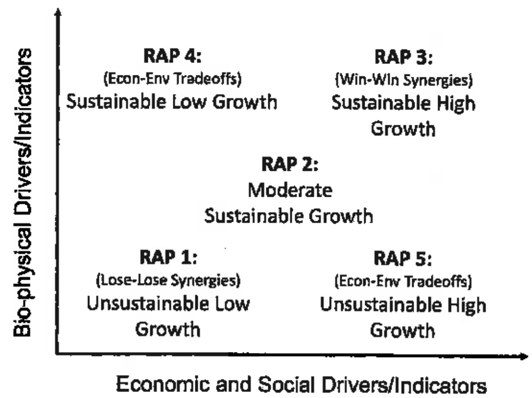

Fig. 5. Five-pathway "synergies and tradeoffs" matrix with pathway descriptions (Antle *et al.*, 2014b).

Why "representative" agricultural pathways and scenarios?

Some of the developers of new socio-economic pathways felt it was important to designate them as "shared" rather than "representative" because they are designed to be multi-dimensional and thus are not easily confined to a single or a small number of variables (in contrast to RCPs, which operate on one dimension; greenhouse-gas emissions) (Kriegler *et al.*, 2012). There is also the hope that many socio-economic pathways might be created so that researchers can select from a "menu" of alternatives. Additionally, some scenario researchers think that there is a tendency to develop future scenarios that are too much like the present, and fail to consider possible "surprises" or possibly unlikely but potentially important alternative futures (van Notten *et al.*, 2005). While these are important considerations, we take the view here that there are also good reasons to propose the development of "representative" socio-economic pathways and more specific RAPs. Two critical, practical issues lead us to this approach; we refer to these issues as the aggregation and dimensionality problems.

Aggregation

Global climate models project climate outcomes that are typically aggregated spatially and temporally (e.g., monthly data for 150-km grid cells). Aggregate economic models are based on data that are aggregated across large numbers of producers and consumers. After these models are simulated, data are typically "downscaled" or disaggregated to smaller grid cells or other spatial units. Similarly, construction of socio-economic pathways and scenarios requires some form of spatial "downscaling" or disaggregation of global trends to subglobal regions, typically to national scales, and then further to subnational regions for impact, adaptation, and vulnerability analysis. This problem was recognized in early climate impact assessment work, and "linear" methods were used that were based on the assumption that all units in a region followed trajectories in proportion to the aggregate value (Gaffin *et al.*, 2004). We observe that the need for "downscaling" is driven by the use of aggregated data and models, and thus we might better describe the problem as one of "disaggregation".

As noted by O'Neill *et al.* (2012), there is a need for a process by which more flexible and meaningful disaggregation can be implemented to create global pathways and scenarios. For example, the first set of SSPs developed by the IAMC contain global population and GDP growth rates as well as national growth rates (International Institute for Applied Systems Analysis, 2012). Linking global pathways to subglobal (say, national) pathways is a way to meaningfully disaggregate so that the subglobal variables are consistent with plausible local storylines, and are not arbitrary values from mechanistic downscaling rules (Zurek and Henrichs, 2007).

Dimensionality

However aggregation and disaggregation are done, one goal of scenario analysis is to understand the sensitivity of results to scenario assumptions, which implies the use of multiple scenarios. Even if this is for a small number of alternative regional pathways for each major global trend, given the number of regions in the world there will be a large number of possible combinations of all trajectories (for example, the current attempts to establish population and GDP trajectories for SSPs are developing national data). Additionally, when we consider that there are multiple RCPs and many climate models, the number of different scenarios to be considered is large. If in addition, an ensemble approach is taken to the IAMs, the number becomes larger yet. When we then consider multiple regional pathways, and multiple subregions, adaptation scenarios, mitigation, and other policy scenarios, the dimensionality rapidly multiplies.

Inevitably, it will be a practical necessity to develop a small number of pathways for shared use as reference scenarios and for standards of intercomparison, model improvement, and impact assessment. This was the original motivation of the RCPs used in GCM simulations, as specific pathways were chosen to represent a family of equally plausible pathways with similar outcomes in order to reduce dimensionality and introduce a standard. Individual teams can design and use as many pathways and scenarios as they wish, but our view is that the "standard" ones will inevitably become the ones that are considered to be representative of major plausible development pathways, much as a subset of the SRES and RCPs have been widely used. We note that research teams can develop other pathway concepts that may be considered "wildcards" or "outliers" to test how climate impacts or adaptation may play out under, e.g., more extreme conditions, but we expect that these outlier pathways will be less widely used by large numbers of research teams, and will not be considered useful reference pathways.

We suspect that if many different pathways are developed, researchers will find that many of them do not result in substantially different implications for impact assessment or adaptation analysis. Thus, what we would see as most useful is a small number of pathways that represent substantially different outcomes for key socio-economic variables. For example, one can imagine a world in which real agricultural commodity prices (prices adjusted for inflation) continue the downward trends observed during the 20th century; and one can also imagine that the world is currently at a turning point (as evidenced by recent spikes and volatility in food prices), and that real agricultural commodity prices will be on an upward trend during the 21st century. Indeed, some global agricultural models predict decreases and some predict increases (Nelson *et al.*, 2014).

Designing Regional RAPs

RAPs must be designed to be part of a logically consistent set of drivers and outcomes from global to regional and local, as illustrated in Figs. 3 and 4. To create pathways and corresponding scenarios at global, regional, or local scales, teams of scientists and other experts with knowledge of the agricultural systems and regions work together through a step-wise process similar to the "Story and Scenario" approach (Alcamo, 2008). AgMIP's experience with the implementation of RAPs has shown that it is a fundamentally *transdisciplinary process* that brings together the various elements of a research team. As Fig. 3 shows, the RAPs are a central element of the research design, and as a result, the RAP development process facilitates the overall design and also improves the communication among the research team that is essential to implement the regional integrated assessment methodology described in Part 1, Chapter 2 in this volume. Another key element of the RAP process is that it brings stakeholders into the research design process at an early stage. This close linkage to stakeholders helps to ensure the legitimacy, credibility, and salience of RAPs to users; key traits of scenarios used in multi-stakeholder environments (Cash *et al.*, 2003).

Valdivia and Antle (2012) have developed an Excel spreadsheet tool called DevRAP (in Beta version) to facilitate this process (Fig. 6). DevRAP provides a structure to guide this process and to record and document the information systematically, and then use it to develop model-specific quantitative scenarios. For example, a version has been designed to provide a structured format for the parameters of the TOA-MD model (Antle and Valdivia, 2011) and crop simulation models; the DevRAP tool can be modified easily to fit other biophysical and economic models.

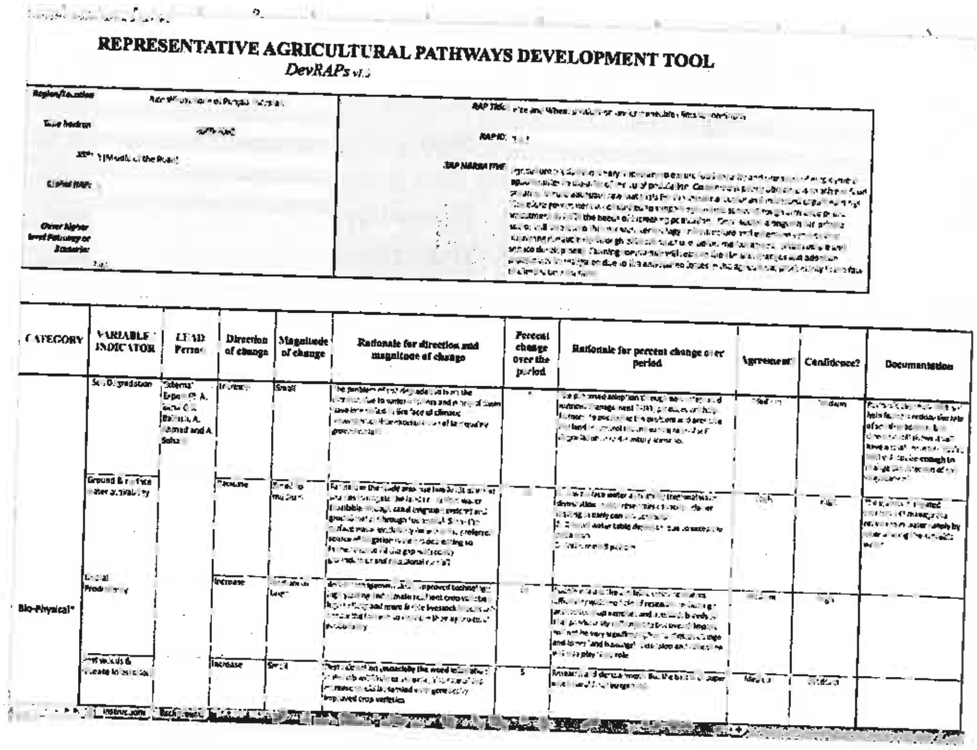

Fig. 6. Example of the RAP matrix in the DevRAP Tool (Antle and Valdivia, 2012), with example for the rice–wheat zone of Punjab, Pakistan. Developed by AgMIP Pakistan regional research team (see Part 2, Chapter 7 in this volume).

To implement RAPs following the matrix in Fig. 6, the team defines a general narrative of the RAPs, identifies socio-economic indicators and develops narratives and quantitative information for them, incorporating appropriate expertise from within the team and also recruiting outside expertise as feasible. Using that format, the team can follow a series of steps for RAPs development:

1. *Define time-period for analysis*: For example, AgMIP has designated three "time-slices" in the 21st century for analysis: early-century (2010–2039), mid-century (2040–2069), and late-century (2070–2099).
2. *Select higher-level pathways*: Following the concept of a nested approach, relevant narratives and quantitative information from selected higher-level pathways (e.g. SSPs, global RAPs) need to be extracted.
3. *Identify variables from higher-level pathways and models*: Selected output variables from higher-level models (e.g., prices, productivity trends, and land-use-change data from global models) can be used as drivers or inputs for a regional model.

4. *RAP research process*:

   a. First meeting:

      i. Start with a "business-as-usual" (BAU) RAP.
      ii Team members identify key parameters that will likely be affected by higher-level pathways and draft RAP narrative.
      iii. Team members are assigned variables for research.
      iv. Team members conduct research — use of templates for reporting and supporting documentation. These templates can be distributed to experts for feedback.

   b. Second meeting:

      i. Team members report findings and discuss storylines for each variable.
      ii. BAU RAP is finalized using the DevRAP tool and complete the following information:

         1. Complete information for each parameter:
         2. Direction, magnitude, and rate of change.
         3. Narrative logic for changes.
         4. Check for internal consistency with higher-level pathways and models' variables.
         5. Ascertain level of agreement among participants.
         6. If level of agreement is low, repeat process until acceptable levels are achieved.
         7. Assess whether one or more parameters need to be revised by other experts or selected for sensitivity analysis.
         8. Document source of information (pathway, model, literature, expert).

      iii. Additional RAPs are identified.
      iv. Process similar to BAU is carried out with additional background research.

   c. Meeting(s) to create additional RAPs — follow similar steps as in a and b.
   d. RAPs distributed to stakeholders and outside experts.

5. *Modelers develop scenarios*: The modeling team utilizes the pathway variables, along with other data, to set model parameters. For each pathway, multiple scenarios are possible, e.g., the modeling team can design a sensitivity analysis by varying parameters over a range consistent with a RAP, or in the context of assessing impacts of climate change, multiple scenarios can be developed to test different adaptation strategies.

RAPs and scenario documentation to address the reproducibility and conversion problems

Two key problems in the story and simulation approach to scenario analysis (SAS; Alcamo, 2008) are caused by the element of subjective judgment needed by a group to translate RAPs into specific model scenarios. There is a one-to-many relation: By design, many different scenarios are consistent with a RAP. The DevRAP tool was developed as a way to address this problem, by structuring and documenting the RAP information and how it is translated into scenarios (model parameters). The DevRAP tool also should address the "conversion problem" in scenario analysis, i.e., how qualitative and more general information in a RAP is translated into specific values of model parameters. It may be coupled with additional techniques, such as the use of Bayesian methods (Kemp-Benedict, 2010) or fuzzy logic (Alcamo, 2008).

Documentation and sharing of RAPs and scenarios

In the spirit of "*shared* socio-economic pathways", one of the goals of socio-economic pathway and scenario development is to create public goods that may be shared to facilitate many applications. Moreover, as we noted above, an important challenge in pathway and scenario design is addressing the aggregation and disaggregation or downscaling problems. An iterative, parallel process of global and regional RAP development would be a way to address this problem in place of mechanistic downscaling. To facilitate this process, it is essential for RAPs and scenarios to be created, documented, and made accessible at low cost to the research community. There are various possible ways for this process to be implemented. Various organizations could archive scenarios and make them publicly available (e.g., AgMIP: www.agmip.org). Data storage systems such as the Dataverse Network may be available. An approach for both global SSPs as well as sector-specific pathways needs to be developed by the research community.

RAPs Developed by AgMIP's Regional Teams in Sub-Saharan Africa and South Asia

One of the key components of AgMIP's regional integrated assessment framework is the development and implementation of RAPs (see Fig 3, and Part 1, Chapter 2 in this volume). AgMIP regional research teams (RRTs) in Sub-Saharan Africa and South Asia are developing and implementing RAPs to incorporate future biophysical and socio-economic conditions into their regional impact and adaptation assessments *ucibility*

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reported in this book. In this section we summarize these RAPs and discuss issues about the development process, outcomes, and future plans as reported by the RRTs.

Regional RAPs and higher-level pathways

As discussed above, RAPs should be designed to be linked to global socio-economic pathways in a logical hierarchical structure (see Fig. 4). AgMIP RRTs have created RAPs that are consistent with SSP 2 (O'Neill, 2012) for the mid-century (2040–2069) period of analysis. Regional RAPs must incorporate trends (e.g., yield and price trends) to translate current production systems into the future conditions defined by the RAPs. Ideally this information should come from global RAPs and global economic models, however global RAPs have not yet been developed beyond the single global RAP utilized by Nelson *et al.* (2014) for harmonization purposes. The teams have used data from the IMPACT global model, which was part of an intercomparison of nine global AEMs. This activity was led by AgMIP and is currently being used as the basis for the development of global RAPs and global impact assessments. Some of the RRTS have also used information from multi-country scenarios developed by CGIAR Climate Change, Agriculture, and Food Security (CCAFS) program for East and West Africa and South Asia (Chaudhury *et al.*, 2012).

Type of RAPs

The strategy for designing regional RAPs was to start with a RAP that represents the case of BAU or current trends continued. Depending on the current conditions, stakeholders' perspectives and research from scientists that participated in the RAP development, the resulting narratives represented trends for higher or lower rates of economic development. The results show that in most cases the teams have developed higher development pathways that would be consistent with the description of RAP 2 in Fig. 5 (see Table 1 at the end of this chapter).

RAP development process

Most of the teams have followed the iterative approach to develop RAPs (see above). They have held between two to three meetings to develop one RAP; they used the first meeting to define a list of key indicators and to assign lead persons to conduct research on each indicator. A second meeting was focused on presenting findings and discussing the storylines for each indicator. In some cases, this meeting included external researchers or invited experts and stakeholders. A third meeting was organized to present the RAPs to stakeholders and obtain their feedback. In some cases (such as the Pakistani and CLIP teams), stakeholders were involved earlier in the process of RAPs (see Table 2 at the end of this chapter). In addition some teams have organized a fourth meeting to revise and finalize the RAP and also to conceptualize and begin the process to develop alternative RAPs.

RAP narratives, key variables and trends

Table 3 (at the end of this chapter) shows the full RAP narratives developed by the RRTs in Sub-Saharan Africa and South Asia. These narratives have several interesting points in common. They all emphasize the key role of governments and agricultural policy. Public and private investment in research and development is also a key element of future socio-economic conditions. These RAPs also express a high level of concern about soil-degradation and water-availability issues and the expectation that technological improvements (e.g., improved cultivars) will help to offset the negative consequences of those biophysical conditions and the possible impacts of climate change.

RRTs have identified several key indicators to describe the future biophysical and socio-economic conditions, although good records of current trends for many indicators proved difficult to obtain. Table 4 (at the end of this chapter) shows the main indicators and their trends expressed in terms of direction (decrease, increase, no change) and magnitude (small, medium, large). Soil degradation has been consistently identified as a major issue by all the teams, which indicates that soil degradation rates will generally increase. However, the magnitude of change varies across cases; for example the magnitude is small in cases where there is more government investment in agriculture, promotion of better soil conservation activities, and increased fertilizer use. Note that these policies help to reduce the rate of soil degradation but do not reverse those conditions completely, except in a few cases where teams have developed a second, more optimistic RAP.

Another important indicator is the increased incidence of pests and diseases. This is particularly interesting because the effects of pests and diseases are not represented in most crop and livestock simulation models. By including these effects in the RAPs (based on secondary information) they can be translated into model parameters and represented in scenarios.

Other farm and household characteristics such as farm size and household size have also been identified as key variables in the RAPs, however the trends vary across cases. Farm size is one of the variables that have been under debate among researchers in each team. In most cases, farm size tends to increase due to farm consolidation and increased off-farm opportunities, which also causes a decrease in household size. This also explains why most of the teams identified increasing trends in off-farm income.

Another set of key variables are the ones related to production inputs, such as fertilizer. In most cases the teams have identified a tendency to increased use of fertilizer due to a combination of lower fertilizer prices (usually tied to government subsidies), increased fertilizer availability, and improved information and extension services. Similarly, the use of improved crop varieties and livestock breeds is likely to increase in most cases.

Other indicators that have also been identified as important in the RAP discussions are the availability of better information and investment in extension and technical services. Most of the teams believe that there is a positive trend in relation to access to better information that could help farmers to make better-informed decisions.

Use of RAPs: Model parameterization

Following the AgMIP approach for integrated assessment of climate change impacts and adaptation (see Fig. 3 and Part 1, Chapter 2 in this volume), the teams have used the RAP information in answering Core Question 2 ("What is the impact of climate change on future agricultural production systems?") and Core Question 3 ("What are the benefits of climate change adaptation?"). Crop, livestock, and economic model parameters have been modified to represent future biophysical and socio-economic conditions (see Part 2, Chapters 1–10 in this volume for specific details). The RRTs used the DevRAP matrix to document the parameter changes, and background and related information. The process of model parameterization was also an iterative process between the teams and the AgMIP economic leaders.

In order to have a better understanding of the parameterization process, two types of variables have been identified in the RAP narratives: Variables that have *direct impacts* on one or more model parameters and variables that have *indirect impacts* on model parameters. For example, increased fertilizer use will affect directly crop model parameters (e.g., amount of mineral fertilizer applied), and economic model parameters (e.g., production costs). Similarly, reduced mineral-fertilizer prices will directly affect the economic models (production costs). On the other hand, policies such as subsidies, investment in infrastructure, and better market access do not have a direct effect on specific model parameters, but help to support the RAP narrative and explain why model parameters such as fertilizer price and fertilizer use are changing.

Stakeholder involvement

A key element of RAPs is the stakeholder involvement in the research process as this increases the legitimacy and credibility of the project activities, in particular of the RAP development. Understandably, in some cases it was challenging to engage stakeholders in a complex modeling activity. However, stakeholder participation in the RAP development process is considered one of the most successful outcomes of the RRT activities by team members (see Table 5 at the end of this chapter). Stakeholders concerns about future conditions (e.g., food security) were a key motivation for them to contribute with their expertise and ideas to develop the RAP narratives. Stakeholders found the RAPs to be an efficient way to link scientists to policymakers, and also a good tool to be used to inform policymaking (Table 5).

Challenges, issues, and positive outcomes

The teams have identified several challenges and issues during the process of creating RAPs. Table 5 shows the challenges and positive outcomes in relation to the process of RAP development.

Identification of indicators: The first challenge that the teams faced was to identify key indicators to describe the RAP. This was particularly difficult due to the fact that developing RAPs is a new approach, and it took some time to understand the process and the ultimate goal of RAPs as a key element in the integrated assessment framework. Nevertheless, the teams were able to identify key indicators and several are common to all the teams. This shows consistency in terms of the perception about what are the key issues of the production systems being modeled even across the diverse agricultural systems of Sub-Saharan Africa and South Asia.

Data availability: Storylines must be accompanied by background information based on current studies, data, or other secondary information. It was challenging for the teams to find reliable data (e.g., current trends of key RAP elements in Table 4), in particular, data at the regional level for non-modeled activities in the production system. The teams recognize that obtaining better data is a point for future improvement.

Agreement on trend directions and magnitudes: The teams have reported that reaching an agreement about the direction and magnitude of changes of indicators was difficult. Disciplinary bias, personal convictions or interests, and little understanding of RAPs were mentioned as the main reasons. For example, some people thought about future conditions as "predictions" of what they think will happen rather than making projections consistent with a narrative to describe plausible future conditions. Reaching agreement for the magnitude of change was more difficult compared to the direction of change. As a next step, the teams will revise those storylines where agreement levels were low by conducting additional research or inviting an expanded group of experts. Sensitivity tests will also help identify parameters and specific trends where particular care must be taken to prevent unrealistic results.

Interaction with stakeholders: The teams reported that one of the most challenging issues was the initial interaction with stakeholders. In particular, explaining the RAP framework and its use within the modeling approach was very difficult. However, most of the teams reported that they succeeded in engaging the stakeholders in the RAP process and obtaining good feedback from them due to multiple meetings and relationship-building.

Despite the challenges faced in developing RAPs, the main positive outcome of the teams is that they succeeded in creating at least one RAP for their region. The RRTs were able to form multi-disciplinary and multi-institutional teams of scientists and involve experts outside of their research teams and stakeholders and come to a level of agreement of what could be a plausible future. The RRTs reported that another positive outcome was the better understanding of how the RAPs fit the integrated assessment framework thanks to the last step of reviewing the RAPs and the model scenarios in conjunction with the AgMIP regional economics team. The teams feel more confident now about developing alternative RAPs and incorporating these into their analysis, which is fertile ground for continuing study.

The way forward: All the RRTs have reported plans for improving the RAPs that had been developed by doing further research on key variables. They will continue developing alternative RAPs for the same region where they developed the first RAP. In addition, RRTs plan to develop RAPs for other regions in their countries. In all cases, the teams are planning to increase stakeholder participation in the next set of project activities and to involve them early in the process.

The AgMIP economic leadership plans to revise the RAP process methodology and tools, create a master list of indicators with detailed definitions that can facilitate the development of RAPs (as noted above, a key issue was to identify main indicators), and provide standard definitions of the indicators being used in the RAPs. AgMIP will also develop ways to archive and document the RAPs and related information in a way that can be used by other researchers.

Conclusions

This chapter presents the conceptual foundations and methods for designing representative agricultural pathways (RAPs) and scenarios that can be coupled with global socio-economic pathways (i.e., SSPs) for agricultural model intercomparison and improvement, and for climate impact, adaptation, and vulnerability assessment, as envisaged by AgMIP and other global and regional modeling projects. AgMIP's goal is to design RAPs for all of the major agricultural regions of the globe. The first step in this process began with regional impact assessment teams created by AgMIP in collaboration with national and international institutions in Sub-Saharan Africa and South Asia (see www.agmip.org). Developing RAPs for these teams has been a "learning by doing" process that has created the capability for better communication and understanding across disciplines and between scientists and stakeholders.

As the regional teams create additional RAPs and implement integrated assessments at the regional and local scales, it will be possible to scale them up to the national and global levels, thus leading to a consistent set of linked global and regional RAPS. These accomplishments will enable a new capability by the agricultural modeling community to conduct agricultural model intercomparisons, and impact, adaptation, and vulnerability assessments consistently across scales. We are confident that this capability will lead to the improvement of agricultural models and to a new generation of improved global and regional assessments.

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Annex 1 — Tables

Table 1. RAPs location and type.

Regional research team	Location	Rate of economic development	Stakeholder involvement
CLIP	Zimbabwe, Matabeleland	High	Yes
CLIP	Zimbabwe, Matabeleland	Low	Yes
CLIP	Mozambique, Manica	High	Yes
CLIP	Mozambique, Manica	Low	Yes
East Africa	Kenya, Embu	High	Yes
SAMIIP	Namibia	High	Yes
SAMIIP	South Africa	High	Yes
CIWARA	Senegal, Nioro	Low	Yes
CIWARA	Senegal, Nioro	High	Yes
South India	India, ANGRAU	High	Some
South India	India, Tamil Nadu	High	Yes
IGB	India, IGB	Low	Yes
IGB	Nepal, IGB	High	No
Pakistan	Pakistan, wheat–rice region	High	Yes
Sri Lanka	Sri Lanka, Kurunegala District	High	Yes
Sri Lanka	Sri Lanka, FECT	High	Yes

Low: Low rate of economic development
High: High rate of economic development

Table 2. RAP development process.

AgMIP RRT	RAP lead person	RAP #	Meeting #	Type of meeting	Goal	Number of attendees	Number of stakeholder attended	Used a facilitator? If yes, name	Status of RAP
IGB India	Harbir Singh	2.1	1	Research team and other scientists	Identify variables to be used in TOA-MD	9	0	Yes, Singh	Regional RAPs (district level) developed. It needs to be updated further for the state as well the whole IGB area (including Nepal and Bangladesh)
		2.1	2	Research team, experts and stakeholders	Explain RAPs and have feedback from stakeholders	29	7	Yes, Singh	
South India	Paramasivam	2.1	1	Research team	Identify variables	8	0	No	RAP process initiation, identification of potential variables, literature review
		2.1	2	Research team, experts	Develop initial RAP narrative	25	0	Balasubramanian	Preliminary RAPs developed for presentation to stakeholder views
		2.1	3	Research team, experts, stakeholders, farmers	Finalize RAP narrative	35	15	Suresh	RAP narrative discussed with participants and finalized
East Africa (Kenya)	Richard Mulwa	2.1	1	Research team	Identification of variables and initial discussions on directions and magnitude of changes	5	0	Mulwa	Variables identified and initial narrative developed, then circulated to research team for further comments

(Continued)

East Africa (Kenya)	Richard Mulwa	2.1	1	Research team	Identification of variables and initial discussions on directions and magnitude of changes	5	0	Mulwa	finalized Variables identified and initial narrative developed, then circulated to research team for further comments

(*Continued*)

Table 2. (*Continued*)

AgMIP RRT	RAP lead person	RAP #	Meeting #	Type of meeting	Goal	Number of attendees	Number of stakeholder attended	Used a facilitator? If yes, name	Status of RAP
		2.1	2	Research team and other experts	Discussion on the magnitudes and direction of variables identified by the research team	15	1	Mulwa/KPC Rao	Initial narrative refined, experts gave opinion and RAP adjusted to fit discussions between experts and research team
		2.1	3	Research team and stakeholders	Clarification on the figures in the RAPs and further comments from stakeholders	25	20	Mulwa	Stakeholder gave opinions on the directions and magnitudes of some variables and we got consensus. Now RAP fully developed
CLIP	Sabine Homann	2.1	1	Research team meets and email exchange	Revise background material, identify variables and define the process of conducting the RAPs	3	0	No	We developed two draft narratives about different scenarios, compared both for consistency, but use only 1.1 for the analysis. Feedback from Roberto Valdivia was used to revise that narrative and verify again with experts
		2.1	2	Research team and stakeholders (crops, livestock, extension)	Report research and assess RAPs with experts	6	4	No	

(*Continued*)

Table 2. *(Continued)*

AgMIP RRT	RAP lead person	RAP #	Meeting #	Type of meeting	Goal	Number of attendees	Number of stakeholder attended	Used a facilitator? If yes, name	Status of RAP
		2.1	3	Research team and stakeholders (crops, livestock, extension)	Document RAPs and share with stakeholders for feedback	6	4	No	
		2.1	4	Research team	Develop final RAP narratives and plan for next RAPs	2	0	No	
		2.2	5	Research team and stakeholders (crops, livestock, extension)	Report research and assess RAPs with experts	6	4	No	
		2.2	6	Research team and stakeholders (crops, livestock, extension)	Document RAPs and share with stakeholders for feedback	6	4	No	
		2.2	7	Research team	Develop final RAP narratives and plan for next RAPs	2	0	No	
		2.1 + 2.2	8	Research team and experts	Revise final RAPs	4	0	No	
SAAMIP (Namibia)	Mogos	2.1	1	Research team and other experts	Identify variables and lead persons per indicator	9	2	No	Final narrative developed, expect to revise it further as we make progress with other RAPs or get better estimates of trends

(Continued)

					RAPs				
		2.1 + 2.2	8	Research team and experts	Revise final RAPs	4	0	No	
SAAMIP (Namibia)	Mogos	2.1	1	Research team and other experts	Identify variables and lead persons per indicator	9	2	No	Final narrative developed, expect to revise it further as we make progress with other RAPs or get better estimates of trends

(Continued)

Table 2. *(Continued)*

AgMIP RRT	RAP lead person	RAP #	Meeting #	Type of meeting	Goal	Number of attendees	Number of stakeholder attended	Used a facilitator? If yes, name	Status of RAP
Sri Lanka Rice Team	R. M. Herath	2.1	1	Research team	Study global and regional RAPs and discuss variables to be considered and identify experts and stake holders to be invited for the meeting and lead persons for variables/areas	11		No	Final narrative developed, expect to revise it further as we make progress with other RAPs or get better estimates of trends
			2	Research team and university academics, research officers, and leading stakeholders	Improve awareness on AgMIP project and get views on climate change impacts on rice farming	77	70	Facilitated by the administrative lead of the AgMIP project	
			3	Research team and university academics, research officers, leading stakeholders, and respective Ministry representative	Discuss views obtained by leading stakeholders to develop RAP needs and possible adaptation strategies	25	19		
		2.1	4	Research team, other experts, and stakeholders	Develop RAPs with the participation of invited experts and stakeholders	98	90		

(Continued)

Table 2. (*Continued*)

AgMIP RRT	RAP lead person	RAP #	Meeting #	Type of meeting	Goal	Number of attendees	Number of stakeholder attended	Used a facilitator? If yes, name	Status of RAP
		2.1	5	Research team, selected lead experts and stakeholders	Explain RAPs developed at the previous meeting and have feedback from experts and stakeholders	15	4	No	
		2.1	6	Research team	Develop final RAP narratives and plan for next RAPs	11		No	
IGB-Nepal	D.B. Thapa Magar	2.1	1	Research team	Identify key variables affecting production system in the future	6	0	No	Draft narrative of RAPs is developed and is still in the process of refinement for getting better estimates of the various variables taken into consideration.
		2.1	2	Research team and multi-disciplinary experts	Sharing about RAPs and discussion with experts	14	0	Yes, D. B. Thapa Magar	
		2.1	3	Research team and stakeholders	Explain RAPs and have feedback from stakeholders	12	8	Yes, D. B. Thapa Magar	
		2.1	4	Research team	Develop (and review) final RAP narratives	3	0	No	

(*Continued*)

				multi-disciplinary experts	and discussion with experts			Magar	
		2.1	3	Research team and stakeholders	Explain RAPs and have feedback from stakeholders	12	8	Yes, D. B. Thapa Magar	
		2.1	4	Research team	Develop (and review) final RAP narratives	3	0	No	

(*Continued*)

Table 2. (*Continued*)

AgMIP RRT	RAP lead person	RAP #	Meeting #	Type of meeting	Goal	Number of attendees	Number of stakeholder attended	Used a facilitator? If yes, name	Status of RAP
Pakistan	M. Ashfaq	2.1	1	Research team	1. Identify variables for different categories 2. Identify lead persons per indicator	10	0	No	Narratives have been developed and revised for current RAP, scenarios have been quantified in the light of developed RAPs and trends have been guesstimated, based on facts and trends
		2.1	2	Research team, other experts, and stakeholders	Report research proposal and discuss each variable according to DevRAP matrix format with experts and stakeholders for their feedback	25	5	Yes, Dr. Abdus Saboor, Dr. Abdul Qudus and Dr. Mrs. Sofia Anwar	
		2.1	3	Research team, other experts, and stakeholders	Discuss variables inconsistencies and have feedback on them from experts and stakeholders	30	10	Yes, Dr. Abdus Saboor, Dr. Abdul Qudus, and Dr. Mrs. Sofia Anwar	
		2.1	4	Research team	Finalize the RAP narratives and discuss about future RAPs	10	0	No	

Table 3. AgMIP regional research teams RAP narratives.

Region and RAP code	RAP narrative
Zimbabwe, Matabeleland — 2.1	***The pessimistic RAP: If there is no change of mindset and way of doing business, food security situation will continue to worsen*** Opportunities for massive increases in agricultural production and productivity exist but are not being exploited. Persisting economic crisis, governments extractive policies (high taxes), and lack of incentives and security for private-sector investment hinder development. Agricultural production and profitability are declining, land is degrading and being underutilized. Labor migration and HIV/AIDS result in labor shortage. Agricultural inputs are in short supply and expensive. Use of improved cultivars will force further decline. With the high cost of production, food imports will further reduce farmers' chances to make a living from agriculture. Poverty levels continue to increase, people become more vulnerable to food insecurity and other risks.
Zimbabwe, Matabeleland — 2.2	***The positive RAP: Zimbabwe stepping out of crisis: For agricultural growth to happen, this depends on the strong assumptions that favorable conditions for private and public investments in the agricultural sector will be created*** Government policy objective is to achieve food security, ensure adequate raw materials for the manufacturing sector and increased export earnings through increased productivity, efficient input use, improved investment and market access, infrastructure, and service development, targeting annual agricultural growth of 9.1% by 2015. A proactive legislation will stipulate land-tenure security, incentives for the banking sector, and revamp research and extension to promote productivity-enhancing technologies for adoption on a large scale. The transformation however starts under extremely difficult conditions, characterized by large account deficit and liquidity challenges and limited direct foreign investment due to lack of clarity on investment security and high interest rates. Underfunded public sector and underperformance of the private sector limit development of the agricultural sector and result in unsustainable import bills for agricultural commodities. Limited employment opportunities in urban areas have curtailed rural–urban migration. Most people remain in rural areas where agriculture is the main livelihood activity due to lack of alternatives.
Mozambique, Manica — 2.1	***Pessimistic RAP: We are about to unlock the potential for growth through market-oriented crop and livestock production*** Government and state policies invest in extractive industries, also with an aim to uplift agriculture and food security. In agriculture, government promotes market-oriented production; subsidies are only during recovery and rehabilitation. Poor infrastructure is a major barrier to agricultural development. Investment in infrastructure is, however, slow. Poor road construction and maintenance restrict private-sector investments in these high-potential agricultural areas (for crops and livestock). Farmers produce beyond subsistence, but fail to access profitable markets (inputs and outputs). Lack of competition input prices tend to be high, output prices generally low. Limited financial capacities and low education levels further restrict farmers' ability for higher benefits from increased agricultural production.

(*Continued*)

Table 3. (*Continued*)

Region and RAP code	RAP narrative
Mozambique, Manica — 2.2	***Optimistic RAP: Expected funding for market-oriented crop and livestock production will be realized*** PEDSA (national strategic plan) will be funded by 2015 and various investment programs will be implemented. Donors' conferences will mobilize resources for funding. PNISA (strategy area in PEDSA, National Investment for Agriculture) will define the requirements for developing the agricultural sector (public/private). Other programs are the Beira Agricultural Growth Corridor for small to medium companies. Private-sector development will be through CEPAGR, infrastructure development through PROIRRI.
Kenya, Embu — 2.1	***Maize production in Embu, Kenya amidst several challenges*** A combination of increasing population, government plans to invest in fertilizer factory, government subsidy on fertilizers, improved economic performance expected to cause a shift from agriculture to service industry, government plans for massive expansion of irrigation (irrigate 1 million ha.), newly devolved county governments etc. are some of the developments expected to change agriculture development in the country.
Senegal, Nioro — 2.1	***Crop production in Nioro with short-term agricultural-policy intervention*** This RAP assumes dominance of state actors in the agricultural-development agenda with the view to bring in fast short-term gains with food-security outcomes to the population. Main interventions will include support for the agricultural-service sector, fertilizer subsidies, and feeder roads (slow). Trading land and human resources to foreign investors, who will in turn develop infrastructure.
Senegal, Nioro — 2.1	***Nioro RAP*** Both the state and the local private sector recognize the need to pursue long-term development in the agricultural sector. Organized civil society demands are factored in. The transformative path will lead to emerging agricultural powerhouse in West Africa with reliance on strong agro-dealers and satisfactory solutions to consumer preferences.
South Africa — 2.1	***Increased commercial agricultural production supported by successful land reform and improved socio-economic conditions*** Agricultural and land-reform policies focus on supporting commercial agricultural production and productivity. Better and well-functioning agricultural credit and market services for both established and emerging farmers. Increased uptake of adaptation strategies by commercial farmers.
Namibia — 2.1	***Higher expectations for agricultural production in the face of continued environmental and socio-economic challenges*** Unintended government policy consequences; lack of good farm management practices specifically to biophysical conditions of land lead to small benefit to the livelihoods. Labor migration to urban areas, non-agricultural activities and impact of HIV/AIDS also leads to labor shortages. Agricultural inputs are not affordable for small-scale farmers. With increases in poverty levels people become more vulnerable to climate change and other risks.

(*Continued*)

Table 3. (*Continued*)

Region and RAP code	RAP narrative
Pakistan, Rice–Wheat Zone of Punjab — 2.1	***Rice–wheat production under vulnerable climatic conditions*** Agriculture production is very important to ensure food security and provision of employment opportunities to the majority of the rural population. Therefore, the government is committed to supporting the agriculture sector through increased public investment to fulfill the needs of an increasing population. The governmental policy objective is to achieve food security, ensure adequate raw materials for the manufacturing sector, and increased export earnings through increased productivity, efficient input use, and better market access, infrastructure, and service development. A proactive legislation will stipulate land-tenure security and incentives for the banking sector and revamp research and extension to promote productivity-enhancing technologies for adoption on a larger scale. The adoption process will be instigated due to the anticipated losses in agricultural productivity in the face of climatic uncertainties.
Sri Lanka, FECT — 2.1	***Government sector plans and policy work for rice-sector improvements*** The government aims to improve food security through self-sufficiency in rice with a framework to promote the rice sector to cope with impacts of variable climate. The government promotes high-yielding and drought-/flood-tolerant rice varieties with policy to encourage the application of organic fertilizers, decreasing the cost on inorganic fertilizers. Government puts more emphasis on improving the agricultural water irrigation/management system to cope with drought conditions.
Sri Lanka, Kurunegala — 2.1	***Intermediate adaptation challenge for increased rice production*** The government aims to invest more in agriculture, shortage of labor with the consequence of decreased population growth and household size. The government promotes improved cultivar and climate-smart technologies but the policy to cut down the use of inorganic fertilizer and phase out the fertilizer subsidy results in deteriorating biophysical conditions, low use of inorganic fertilizer, less water, reduced farm sizes which lead to low benefit from the improved cultivar.
North India, IGB — 2.1	***Cereals-production system under climate change*** Climate change has an adverse impact on agricultural production system in the Indo-Gangetic region where rice–wheat is the predominant cropping system, which contributes to national food security. Global trends suggest that rice–wheat production in the region will be adversely affected by climate change. Though the government adopts long-term and short-term policy measures, rice–wheat production costs increase substantially. Imports are inadequate to meet domestic demand. Incentives in the form of assured prices (minimum support prices) are inadequate to enhance agricultural production to meet food demand. Hence, government liberalizes imports of food grains, invests in food chain logistics, and boost research and development for new crop cultivars to boost agricultural production for ensuring food security.

(*Continued*)

Table 3. (*Continued*)

Region and RAP code	RAP narrative
Nepal, Banke — 2.1	***Climate change impacts and adaptation strategies for rice–wheat production system in Terai region of Nepal*** Climate change remains as a key challenge for a country like Nepal where subsistence-based and rainfed agriculture system is dominant. Heavy reliance on suitable climatic conditions for agricultural production always imposes serious risk to the agricultural sector in Nepal. On the other hand, having limited capacity to adapt and respond to the climatic stresses, rural poor farmers in the country face the challenge of adapting to climate change impacts. However, the government will prioritize its programs to minimize the loss from climate change impacts and reduce the vulnerability of the people. Along with the support programs such as agricultural insurance and input subsidies, the government efforts and investments will be increased for extending irrigation services, agricultural mechanization, and developing disaster risk-management practices. The support for agricultural research, education, and extension programs will also be increased for developing and disseminating climate change adaptation agricultural technologies to the farmers. This will support them as they adapt to climate change and reduce their vulnerability.
South India, Tamil Nadu — 2.1	***RAPs for Tamil Nadu*** There will be a small increase in crop diversity due to the need to combat the climate and market risks as both of these might become more volatile in the future. Water quality and water availability for agriculture will decrease due to pollution of water bodies, and competition for water from other sources, but water-use efficiency in agriculture will increase due to technological progress. Soil quality will decline by a small-to-medium extent, due to pollution, and intensive cultivation will be caused by a shrinking land base for agriculture. Most subsidies are likely to decline while prices of agricultural commodities will increase. Farm size and wage rates will increase. Mechanization and energy-use intensity in agriculture will increase. Share of agriculture in overall economy will decrease with increase in inequality. Significant decline in poverty will be associated with a decrease in family size and increase in non-farm income. There will not be significant changes in food imports, while yield of important crops will increase due to technological progress in agriculture. Fertilizer-use intensity and fertilizer productivity will increase. Corporate role in agriculture will increase with improved increase in commodity groups.
South India, Andhra Pradesh — 2.1.1	***Maize production in India*** With a high cost of production and degraded natural resources, profitability in agriculture may be further reduced, making agriculture unprofitable. This requires more opportunities in non-agricultural income and increased technological interventions. However, opportunities for massive increases in agricultural production and productivity exist. Use of improved cultivars and mechanization will be increased and use of critical interventions may lead to increases in productivity and efficient use of resources.

Table 4. AgMIP regional research teams RAP trends.

Sub-Saharan Africa teams

Variable	CLIP – R1 Zimb	CLIP – R2 Zimb	CLIP – R1 Mozamb	CLIP – R2 Mozamb	East Africa Embu, KE	West Africa R1 Nioro	West Africa R2 Nioro	SAAMIP South Africa	SAAMIP Namibia
Soil degradation	Moderate decrease	Large increase	Moderate increase	Small decrease	Moderate increase	Moderate increase	Moderate decrease	Moderate increase	Large increase
Pest and diseases	Not included	Not included	Not included	Not included	Small increase	Not included	Not included	Not included	Not included
Extreme events	Moderate increase	Moderate increase	Not included	Not included	Large increase	Not included	Not included	Not included	Not included
Water availability	Not included	Not included	Not included	Not included	Large decrease	Not included	Not included	Moderate decrease	Moderate decrease
Farm size	Moderate decrease	Moderate decrease	No change	No change	Large decrease	Large increase	Moderate increase	Moderate increase	Moderate decrease
Household size	Moderate increase	Small decrease	Small increase	Small increase	Moderate increase	Moderate decrease	Moderate decrease	Not included	Moderate decrease
Herd size	Moderate increase	Moderate decrease	Small increase	Moderate increase	Not included	Large increase	Moderate decrease	Not included	Not included
Livestock Productivity	Moderate increase	Moderate decrease	Small increase	Large increase	Not included	Moderate increase	Moderate increase	Not included	Not included
Fertilizer prices	No change	Large increase	Moderate decrease	Moderate decrease	Large increase	No change	Small increase	Not included	Not included
Fertilizer use	Moderate increase	Large decrease	Moderate decrease	Moderate increase	Moderate increase	Not included	Not included	Moderate increase	Moderate increase
Subsidies (inputs)	Moderate increase	No change	No change	No change	Not included	Small increase	Moderate decrease	Not included	Not included
Off-farm income	Moderate decrease	Large decrease	Moderate increase	Moderate increase	Large increase	Moderate increase	Moderate increase	Moderate increase	Large decrease
Improved crop use	Large increase	Large decrease	Small increase	Moderate increase	Not included	Moderate increase	Large increase	Moderate increase	No change
Information availability	Not included	Not included	Not included	Not included	Large increase	Not included	Not included	Not included	Not included
Public invest in Agriculture	Moderate increase	No change	Moderate decrease	Moderate increase	Not included	Not included	Not included	Moderate increase	Small increase
Labor availability	Small increase	Moderate decrease	Moderate increase	Moderate increase	Large decrease	Not included	Not included	Not included	Not included

Direction and magnitude
No change
Small increase
Moderate increase
Large increase
Small decrease
Moderate decrease
Large decrease
Not included in RAP or under revision

South Asia teams

Variable	Pakistan	Sri Lanka - FECT	Sri Lanka - Kaneg	IGB North India	IGB Nepal	South India TNAU	South India ANGRAU
Soil degradation	Small increase	Moderate increase	Small increase	Moderate increase	Moderate increase	Small increase	Small increase
Pest and diseases	Small increase	Not included	Not included	Not included	Moderate increase	Moderate decrease	Small increase
Extreme events	Moderate increase	Moderate increase	Not included	Not included	Moderate increase	Not included	Small increase
Water availability	Large decrease	Not included	Moderate decrease	Not included	Not included	Not included	Small decrease
Farm size	Small decrease	Not included	Small decrease	Moderate decrease	Small decrease	Moderate increase	Moderate increase
Household size	Moderate increase	Small decrease	Small decrease	Moderate decrease	Not included	Small decrease	Not included
Herd size	Moderate increase	Not included	Not included	Not included	Not included	Not included	Moderate increase
Livestock Productivity	Not included	Not included	Not included	Not included	Not included	Not included	Not included
Fertilizer prices	Moderate increase	Large increase	Moderate increase	Not included	Moderate increase	Small increase	Large increase
Fertilizer use	Moderate increase	Not included	Not included	Not included	Not included	Not included	Large decrease
Subsidies (inputs)	Moderate increase	Large decrease	Moderate decrease	Small increase	Moderate increase	Small decrease	Moderate decrease
Off-farm income	Moderate increase	Not included	Not included	Not included	Moderate increase	Moderate increase	Moderate increase
Improved crop use	Large increase	Moderate increase	Moderate decrease	Not included	Moderate increase	Small increase	Moderate increase
Information availability	Moderate increase	Moderate increase	Not included	Moderate increase	Moderate increase	Not included	Large increase
Public invest in Agriculture	Moderate increase	Moderate increase	Small increase	Not included	Moderate increase	Not included	Moderate decrease
Labor availability	Small increase	Large decrease	Large decrease	Not included	Large decrease	Moderate decrease	Large decrease

Direction and magnitude
No change
Small increase
Moderate increase
Large increase
Small decrease
Moderate decrease
Large decrease
Not included in RAP or under revision

Table 5. RAP development process, challenges, and outcomes.

Team	Challenges, issues	What worked Positive outcomes	Next steps
IGB India	The RAP development process requires a lot of patience to identify important issues/variables with help from a diverse group of stakeholders who often have divergent views/opinions.	The feedback from the scientists in the first meeting was very logical. During the second meeting, the stakeholders appreciated the process and utility of developing RAPs for a likely scenario of farming systems under climate change.	The district-level RAP is being finalized and, if approved, the team plans to update the RAP for the regional level (covering the whole IGB).
South India	Visualizing specific scenario-based RAPs.	Identification variables likely to be impacted, general directions and magnitudes of change from literature.	Arrangements for RAPs meet with interdisciplinary scientists.
	Disciplinary bias, personal convictions of experts, visualizing scenario-based future outcomes, anticipating policy changes and system changes were major challenges to arriving at a consensus.	Able to reach consensus on major variables likely to be impacted, their direction and magnitudes of change with levels of agreements and convictions.	Arrangements for wider stakeholders meet along with interdisciplinary scientists and farmers.
	Narrowing perception differences between farmers who concentrate on short-term variability issues and expert and stakeholder views on climate change.	RAP finalized. Participants were initially asked for their views and later presented with earlier RAP drafts by experts. In most cases general directions of change coincided and magnitudes were also more or less similar.	Incorporation of variables identified into integrated climate change impact assessment of agricultural-production systems.

(*Continued*)

Table 5. (*Continued*)

Team	Challenges, issues	What worked Positive outcomes	Next steps
East Africa (Kenya)	In the initial stages, it was difficult to identify the variables in each category. The broad categorization (grouping) of variables helped us. However, coming up with the relevant variables for each category was the biggest challenge. In the end we managed to agree on the variables we used in our RAP.	We managed to agree on the variables, and the research team appreciated the importance of RAPs. This enabled us to move to the next stage.	Maintain the same research team for Phase II.
	The first challenge was identifying experts with interest on climate change issues. The biggest challenge, however, was agreeing on the magnitude and directions of the different variables. The experts also helped with addition of a few variables not included in the initial stage. Agreements on the general direction were relatively easier but agreeing on magnitude was quite difficult.	Disagreement, especially on the magnitude of change was pronounced in this meeting, but finally we managed to agree on all the variables we had identified. Experts also helped with identification of more variables.	If there is any extension of the project, then we will have new RAPs for the new localities we will be working in.
	The challenge was first explaining to stakeholders why we took the direction of RAPs. Some wanted to know whether it had been applied elsewhere. Once this was clear, there were disagreements with magnitude and direction of some variables such as farm size. However at the end, there was consensus and everyone appreciated the effort.	We managed to explain to stakeholders why RAPs were necessary and they were able to appreciate our efforts in the whole process.	We promised to share the RAP with stakeholders so they can give us any extra inputs if they have.

(*Continued*)

Table 5. (*Continued*)

Team	Challenges, issues	What worked Positive outcomes	Next steps
CLIP	RAPS were a new concept, with no previous experience within the project team and limited support from other scientists. We used the comparison of RAPS for two scenarios and expanded the list of variables to verify the projections as perceived by the stakeholders. Economic leadership feedback was useful, and highlighted the need for additional expertise to verify consistency and plausibility. Stakeholders' differentiation of future scenarios with and without climate change was not possible — those differences had to be incorporated later, based on experts estimations. A limitation might be that the African socio-political systems are very dynamic and often with poor governance structures — assumptions and therewith the percentages of change can change dramatically.	To work within a limited budget we had decided for structured discussion with few knowledgeable stakeholders (mostly government staff at provincial level) to assess the RAPs, rather than a participatory multi-stakeholder workshop. The approach proved to be effective. Few variables were also verified through the private sector, e.g., expected price trends. The discussions were engaged and stimulated further thinking about the complexity, causes and effects of policy interventions on farming systems. It provided valuable information on the socio-economic context, challenges and investments, that will be useful also for other projects.	The same approach was implemented in Mozambique — the final review is outstanding. In Malawi, RAPs still need to be assessed. Cross-country comparison should give valuable insights on context specificity and complexity of development pathways.

(*Continued*)

Table 5. (*Continued*)

Team	Challenges, issues	What worked Positive outcomes	Next steps
SAAMIP Namibia	The challenge was to explain the concepts of scenario development to stakeholders. Stakeholders and experts tend to focus on their expertise area only. For example, in Namibia, where livestock is important, stakeholders would prioritize looking at the impacts of climate change on livestock and rangeland.	Each participant contributed positively to the discussion and looked at the future with objectivity.	For Namibia, for this phase of the project what we have collected is final, for the future we hope to include more RAPs.
Sri Lanka Rice Team	There was a challenge of getting the views of all, since a large number of experts and stakeholders had been invited for certain meetings. However, this was overcome by having group discussions. Since experts of different discipline were put together, everyone tried to show that variables that fell into their own discipline will be affected more than other variables. It was difficult to come to an agreement on the exact magnitude of specific variables and this highlighted the need for comprehensive investigations.	The third and fifth meetings were very successful since only selected experts and stakeholders only from the rice sector were invited. Experts and stakeholders had come with preparation and background information. They got the opportunity to discuss in detail future planning with respect to adapting to climate change, taking into consideration traditional knowledge and a systems approach.	It was expected to review these RAPs further and to develop other possible RAPs to address the challenges. It also very much highlighted the need for development of a comprehensive related database for region-/crop-/farming-system-specific information for precise predictions.

(*Continued*)

Table 5. (*Continued*)

Team	Challenges, issues	What worked Positive outcomes	Next steps
IGB Nepal	Identifying the key variables affecting the production system, estimating their direction and magnitude of change in the future and incorporating their effect in the production system is challenging.	Review of the past trends and future projections of climate, technology development, and production trends and socio-economic developments (labor issues, input and output price) and interaction with the multi-disciplinary experts and stakeholders was useful to identify and estimate the direction of changes in key variables that affect the production system.	Need further review of RAPs with consultations with the research-team members and multi-disciplinary experts to refine the various variables taken into consideration for the production-system analysis.
Pakistan	Identification of the socio-economic, agronomic, and management variables that stakeholders (policymakers, researchers, farmers, etc.) could use as adaptation option(s) and then assess the aggregate effect of these options as a package on future agriculture system in the face of climate change Unavailability of region specific *ex-ante* analytical impact assessments studies for cropping system and livestock. Minor activities and livestock (meat and milk) were included in the RAPs without modeled data (like IMPACT trends). For the future, such modeled estimates are required for generating regional-level RAPs and making them consistent with the global-level RAPs.	A multi-disciplinary team of scientists (economists, plant breeders, irrigation specialists, soil scientists, agronomists, policymakers, progressive farmers, extensionists, and other experts) was established. Based on the draft narrative parameters, a comprehensive RAP package was developed by involving the key stakeholders in the process. The draft RAP was given to experts, researchers, and the project team for their insight after discussion with their respective colleagues. Thus it helped in determining the direction and extent of the impacts imparted by these adaptation practices.	Alternative RAPs would be developed and their possible impacts would be analyzed. For the mixed, cotton–wheat and rainfed cropping zones, RAPs will also be developed and impacts will be assessed. Alternative RAPs will be developed for these cropping zones and comparisons of these RAPs could also be made for best RAP selection. Continuous feedback from the policymakers and other stakeholders will be sought in order to refine the adaptation packages and quantify their impacts.

(*Continued*)

Table 5. (*Continued*)

Team	Challenges, issues	What worked Positive outcomes	Next steps
		Final regional RAPs were used by crop and economic modeling teams for scenario development, parameters, and trend quantification. These regional RAPs developed by the AgMIP-Pakistan team for rice–wheat cropping system could be used for other impact assessment studies in the future.	Different meetings have been planned to be organized at the Food and Agriculture Wing, Planning Commission Islamabad, Punjab Economic Research Institute Lahore, and in other educational and research institutes of the Province.

Source: AgMIP regional research teams.

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