Sociotechnical Imaginaries of Agro-Climate Foresight Models: the Cases of Agrimonde and AgMIP

Sheila Heimenrath[1]

Abstract: A wide range of disciplinary scholars (computer modelers, climatologists, economists, crop and soil scientists, biologists, social scientists, among others) have contributed concepts and tools during the last decades to develop models to assess and confront environmental, agricultural, social, economic and climate challenges and their impact on food security as a multiscalar public issue (global, regional, national and local). Environmental degradation, social inequality, biodiversity loss, the accumulation of greenhouse gases in the atmosphere and their cascading effects through the entire biosphere and hydrosphere are of concern for global food security and socioeconomic and health crises. Drawing on the analytic category of sociotechnical imaginaries, facilitating theorizing across disciplinary boundaries, this article approaches foresight exercises and modeling experiences of agricultural systems to reflect on the "collectively held, institutionally stabilized and publicly performed visions of desirable futures" (Jasanoff 2015b, 322) embedded in the experiences of two foresight communities. On the one hand, this work engages and discusses the Agrimonde and Agrimonde-Terra foresight exercises exploring how to feed nine billion people by 2050 in a sustainable way, and the relationship between land use and global food security, respectively (Paillard et al. 2014, Le Mouël et al. 2018). On the other, the case study of a transdisciplinary network of climate and agricultural systems modelers from developed and developing nations, the Agricultural Model Intercomparison and Improvement Project (AgMIP) is characterized and analyzed (Rosenzweig et al. 2021, Rosenzweig and Hillel 2015). Tracing the sociotechnical imaginaries of these case studies, this article explores the configuration of future expectations, resource allocation, regulation and institutionalization of visions of the collective good related to agricultural knowledge, science and technology.

Introduction

Researchers increasingly use scenarios designed through foresight processes to deal with future uncertainties that will affect humans and the environment in planning for a changing climate and its associated limits to agriculture and food systems. Foresight activities, including scenario development and quantitative modeling have played a critical role in analyses prepared for the Intergovernmental Panel on Climate Change (IPCC). Defined by the IPCC (2007, 86) as "plausible and often simplified description of how the future may develop", scenarios represent an attempt to facilitate thinking about the possible consequences of different courses of action. In this regard, scenario development, modeling and foresight exercises are part of the efforts exploring options which guide international policymaking and research to inform choices across many sectors and decision-making levels at different geographic, administrative and temporal scales (Wiebe et al.

2018).

In 2004, a European Foresight Monitoring Network (EFMN), and a European Foresight Platform (EFP)[2] were launched. This Europe-wide network initiative mapped foresight exercises for rethinking our future conducted in Europe but also in other regions of the world covering countries such as Japan, China, Korea, US, Canada and Brazil. This effort to map and retool foresight exercises was aimed at contributing to the analysis of changes in the global research system and their possible implications for research policy (Giesecke et al. 2009; 2008).

In order to contribute to the understanding of the current state of agro-climate foresight models, addressing the complex challenges affecting food security as a multiscalar public issue, this article draws on the analytic category of sociotechnical imaginaries, a theoretical and methodological approach elaborated to facilitate analytical work across disciplinary boundaries. In this sense, this article approaches modeling experiences and foresight exercises of agricultural systems to reflect on the "collectively held, institutionally stabilized and publicly performed visions of desirable futures" (Jasanoff 2015b, 322) embedded in the experiences of modeling/foresight communities.

Work in the sociotechnical imaginaries' framework invites us to explore the trajectories of new scientific ideas and technologies and the social arrangements and rearrangements they support. This analytical approach, tracing the embedding of ideas into institutions and materialities allows to follow how the imagined is translated into durable routines and explore moments of resistance as well as the phenomenon of extension, the complex of processes by which unconventional ideas gain traction, acquire strength, cross scales overcoming geopolitical boundaries, persist through time, remaining continually open ended and subject to revision.

Actor network theory (ANT) is a significant thread in the genealogy that sociotechnical imaginaries draw upon. ANT's vision urges us not to take binaries for granted like nature-culture, science-society and human-nonhuman, "encouraging greater attentiveness to forms of distributed agency and action - and hence of dispersed causality - that disciplinary training tends to simplify or dismiss" (Jasanoff 2015a, 16).

The analysis of the development of sociotechnical imaginaries bridges and reveals dynamic interplay between binaries "that are too often kept analytically distinct" (Jasanoff 2015b, 322) like descriptive and normative, structure and agency, material and mental, local and translocal. As an analytic concept, sociotechnical imaginary combines agency with the structured hardness of technological systems, policy styles, organizational and political cultures.

The two case studies of modeling/foresight and scenario development that this article approaches exemplify the development of anticipatory knowledge practices that 'turn the future into an object of scientific enquiry and political intervention' (Aykut et al. 2019). Alongside, foresight activities configure scenarios of debate in which a variety of visions of the future, technologies of knowledge production and social groups engage in dynamic interplay between epistemic and political dimensions of production, assessment and legitimation of knowledge and its use in policy environments. In this sense, the making and use of global models, foresight exercises, scenario development and their methodological choices raise questions about the actors participating in their elaboration and evaluation, the matters of concern and dimensions of the problem taken into account, the assumptions and sets of knowledge on which they are based.

In its initial formulation, sociotechnical imaginaries were defined as "collectively imagined forms of social life and social order reflected in the design and fulfillment of nation-specific scientific and/or technological projects" (Jasanoff and Kim 2009, 120). This elaboration was refined and extended to include "the myriad ways in which scientific and technological visions enter into the assemblages of materiality, meaning and morality that constitute robust forms of social life" (Jasanoff and Kim 2015, 4). Redefined as not limited to nation-states the notion of sociotechnical imaginaries was reconceptualized as visions that can be articulated and propagated by other organized groups such as corporations, social movements and professional societies. Articulated and circulated by a wide range of collectives, the concept of sociotechnical imaginaries offers a framework for exploring the ways "science and technology have been involved in efforts to reimagine and reinvent human societies" (Jasanoff 2015, 321).

In the next sections of this work, we explore the visions co-produced within two modeling/ foresight/ scenario development communities. The first section approaches two foresight/ modeling/ scenario development exercises jointly undertaken over a ten-year period (2006-2016) by two French research organizations: the French Agricultural Research Centre for International Development (CIRAD, by its French acronym) and the National Institute of Agricultural Research[3] (INRA, by its French acronym). The first exercise, Agrimonde, gathered a panel of French experts with the aim to explore pathways to feeding nine billion people in 2050 in a sustainable way (Paillard et al. 2014). The second, Agrimonde Terra, launched in 2012, was about land use and food security in 2050 (Le Mouël et al. 2018). Both projects, Agrimonde and Agrimonde Terra, are characterized, compared and analyzed focusing on their contributions to the debate on methodological choice in the development of agricultural models for global food security.

The second section engages with the Agricultural Model Intercomparison and Improvement Project (AgMIP), launched in 2010, a member of the Global Alliance for Climate-Smart Agriculture[4] launched the same year. The concept of Climate-Smart Agriculture (CSA) was officially presented at The Hague Conference on Agriculture, Food Security and Climate Change in 2010 through the paper "Climate-Smart Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation" (FAO 2010). CSA was defined in this FAO paper as "agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes GHG (mitigation), and enhances achievement of national food security and development goals" (FAO 2010, ii). This section follows the global circulation of the ideas, visions and aspirations about scientific and technological futures initially associated to the concept of CSA examining how it both embeds and is embedded in institutions, instruments, discourses, economic, material and social infrastructures. Following the trajectories through which sociotechnical imaginaries can become integrated into the discourses and practices of governance and structure the life worlds of larger groups, the second section of this article characterizes AgMIP focusing on the work of its research methods team on Representative Agricultural Pathways (RAPs); in particular, on its development of scenarios for regional integrated assessment of climate change impacts, vulnerability, and adaptation (Valdivia et al. 2021; 2015; Rosenzweig et al. 2021; Rosenzweig and Hillel 2015; Hillel and Rosenzweig 2012).

The last section of this article discusses the ways in which the sociotechnical imaginaries theoretical and methodological approach can complement other analytical approaches on global modeling and foresight like the new political sociology of science, neo-institutionalist field theory (Cornilleau 2019) and economic sociology (Dorin and Joly 2019) to contribute to reflexive and responsible foundations for practices of future-making and sociotechnical transformations. Tracing the sociotechnical imaginaries of the cases briefly presented above, this article explores the configuration of future expectations, resource allocation, regulation and institutionalization of visions of the collective good related to agricultural knowledge, science and technology.

The Agrimonde and Agrimonde-Terra foresight exercises: From the consideration of the Millennium Ecosystem Assessment (MA) and International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD) to embedding the sociotechnical imaginaries of a transition to agroecology

A Foresight exercise to explore pathways to feeding nine billion people in 2050 in a sustainable way: The Agrimonde Project interactions with the MA and IAASTD

A panel of French experts developed Agrimonde with the goal of building and analyzing contrasting scenarios of the world's food and agricultural systems by 2050, to anticipate the key issues research will have to address. This foresight exercise was supported since its initial phase by two main French agricultural research institutions: the *Centre de coopération internationale en recherche agronomique pour le développement* (CIRAD) and the *Institut national de la recherche agronomique* (INRA) (Paillard et al. 2014).

Agrimonde, in its initial phase, was embedded in the European Foresight Platform (EFP)[5] as part of the European Foresight Monitoring Network (EFMN) that mapped over 2000 initiatives between 2004 and 2008[6]. Mapping and analyzing foresight exercises in European Union Member States and other countries such as Japan, China, Korea, the US, Canada and Brazil, the EFMN identified broad areas of future concern in Science and Technology for Europe and the world (Giesecke et al. 2009; 2008).

The future as a research object in France is not conceived as "something already decided, something revealed bit by bit, but rather as something to be created" (Lattre-Gasquet and Treyer 2016, 37). Faced with the uncertainty of the future, four attitudes are distinguished: passive (submit to change); reactive (await change to react); preactive (preparing for an anticipated change); and proactive (acting to provoke a desired change) (Lattre-Gasquet and Treyer 2016, 37).

The CIRAD-INRA Agrimonde initiative was stimulated by the work of the Millennium Ecosystem Assessment (MA) and the International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). The Agrimonde scenarios in its initial phase were built with reference and by contrast to the Millennium Ecosystem Scenarios (Paillard et al. 2014, 50-54). The choice of constructing scenarios with reference to those of the Millennium Ecosystem Assessment led to the selection of the same timeline, 2050, and the same geographic zoning.

The Millennium Ecosystem Assessment (MA)[7] - involving the work of approximately 1,360 experts from 95 countries - took place over a four-year period with the participation of several scientific disciplines (among them biology, economics and sociology). The MA reports, published in 2005, provided a state-of-the-art scientific appraisal of the condition and trends in the world's ecosystems, the services they provide (such as clean water, food, forest products, flood control and natural resources), and the options to restore, conserve or enhance the sustainable use of ecosystems.

Initiated in 2001, the MA has highlighted the deterioration of ecosystems and the consequences of ecosystem change for human wellbeing. "The history of human civilization has many examples of social upheaval associated with ecosystem service failure at the local or regional scale" (Hassan et al. 2005, 23). However, the MA warned that compared with any other time in history, human impacts are global in reach, ubiquitous and of greater intensity than at any time in the past. "Displacement of the problem to other places and future generations, or starting afresh in a new place, are no longer viable options" (Hassan et al. 2005, 23). In addition to assessments, the MA experts built four scenarios that focus on ecosystem change and the impacts on human wellbeing. Despite increasing food supply, the MA recognized that dramatic changes in the quantity and quality of ecosystem services with some services diminished or degraded, that are projected to be further impaired, represent a threat for food security. Quantitative projections using models are important elements of the MA scenarios. Nevertheless, models exist to quantify many, but not all, aspects of the MA scenarios.

A number of global assessment initiatives have been arranged, established and adopted in recent decades, from intergovernmental structures like the Intergovernmental Panel on Climate Change (IPCC) founded in 1988, to nongovernmental governance structures like the Millennium Ecosystem Assessment called by the United Nations Secretary-General in 2000. Between 2003 and 2008, "to encourage local and global debate on the future of agricultural science and technology" and responding "to critiques of top-down, northern dominated expert assessment of the past" (Scoones 2009), the International Assessment of Agricultural Knowledge, Science and Technology for Development was designed and implemented, involving over 400 scientists worldwide (McIntyre et al. 2009).

The IAASTD was initiated in 2002 by the World Bank and the Food and Agriculture Organization of the United Nations (FAO) as a global consultative process. During 2003, consultations were held involving over 800 participants from relevant stakeholder groups, governments, the private sector and civil society, overseen by an international multistakeholder steering committee. Based on these consultations, the steering committee recommended that an international assessment was needed to examine the role of agricultural knowledge, science and technology (AKST) in reducing hunger and poverty, improving rural livelihoods and facilitating environmentally, socially and economically sustainable development.

The IAASTD governance structure was a hybrid of the Intergovernmental Panel on Climate Change (IPCC) and the nongovernmental Millennium Ecosystem Assessment (MA). The concept of IAASTD was endorsed as a multi-thematic, multi-spatial, multi-temporal intergovernmental process cosponsored by the Food and Agricultural Organization of the United Nations (FAO), the Global Environmental Facility (GEF), United Nations Development Programme (UNDP), United Nations Environment Programme (UNEP), United Nations Educational, Scientific and Cultural Organization (UNESCO), the World Health Organization (WHO) and the World Bank (McIntyre et al. 2009).

Debates and controversies within the IAASTD process centered around the role of top-down expert assessments versus participatory approaches to knowledge generation and the role of biotechnology and transgenic crops in sustainable development. In the global climate change policy arena, the consideration of adaptation and mitigation in two separate negotiation streams was placed under scrutiny for limiting capacities to build synergies between them (Lipper and Zilberman 2018).

In order to guide research orientations in the field of agronomy and food, a scenario approach was adopted within the CIRAD-INRA Agrimonde initiative to inaugurate a process of debates and interactions on the subject at a national scale, as well as promoting participation in international debates such as the IAASTD. The first plenary meeting of the IAASTD took place in September 2004. Several French researchers were involved in the IAASTD process and the Agrimonde foresight exercise was launched with the aim of building capacities to support them, contributing to their proactive participation in this global assessment initiative and to pluralize the visions and scenarios discussed in this arena (Lattre-Gasquet and Treyer 2016).

To meet these objectives, the Agrimonde system[8] was developed for facilitating collective scenario building to compare a business-as-usual scenario with an agroecological scenario, within an effort focused on two questions: "How and through what innovation pathways could a population of nine billion people be adequately fed, while preserving ecosystems integrity? What should be the priority issues for agricultural research?" (Lattre-Gasquet and Treyer 2016, 39).

The Agrimonde initiative not only attempted to pluralize the substance of the scenarios considered but also the methods to develop and represent them, questioning the dominance of economic models of global commodity markets, like for instance, the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) developed at the International Food Policy Research Institute (IFPRI), as the basis for assessing global food security. The IMPACT model has been used in various global assessment studies like the Millennium Ecosystem Assessment and IAASTD (Rosegrant 2012, 10). The IMPACT model, like other models associated to industrial agricultural monocultures, "totally ignore how biodiversity, plant-plant and plant-animal synergies below and above the ground (from soil fungi to trees, from soil bacteria or worms to cattle), can boost both land productivity and resilience to climate change, soil fertility, water saving, nutritional security and biodiversity conservation" (Dorin and Joly 2020, 4). By eliding observable diversity, mainstream models only represent industrial production systems promoted by policies in favor of large-scale industrial monocultures since the Green Revolution. Thus, more complex biodiverse production systems, such as those based on agroecology and biological synergies are blacklisted as sociotechnical policy options (Dorin and Joly 2020, 5).

To account for different types of innovation, conventional and agroecological, Agrimonde developed - through more transparent assumptions - an alternative quantitative framework, based on physical balances between biomass resources and uses. A specific quantitative tool called *Agribiom*[9] was developed and used to produce quantitative scenarios concerning world food production, trade and use of biomass. "The sets formed by quantitative assumptions and the corresponding resource-use balances constituted quantitative scenarios... When experts formulated assumptions on diet, land use, yields or inter-regional trade, they had to analyze all their implications and ramifications. Through this process, they enhanced the basic quantitative assumptions with a set of qualitative assumptions" (Treyer et al. 2014, 4).

Scanning and processing almost thirty million pieces of data mostly from Faostat, the Agribiom model allowed participants (agronomists, sociologists, economists among other experts) to work together revisiting past structural evolutions before turning to discussions on future qualitative scenarios and translating them into quantitative parameters, checking their global consistency and their implications. Statistics, models and scenarios were used to "foster collective learning, stimulate imagination and reduce inconsistences" (Dorin and Joly 2020, 7).

The final days of the first foresight Agrimonde exercise, as well as the elaboration of its final report, converged with the final days of the IAASTD and the elaboration of its global assessment report, and the starting of the global food crisis with cereal prices triggering a period of food riots highlighting agricultural knowledge, science and technology as one of the most important issues on the political agendas of many countries and international organizations.

The IAASTD Global Report (McIntyre et al. 2009, 268) drew attention to a trend toward increasing citizen participation in the formulation of development strategies and sectoral policy documents such as agricultural sector strategies, increasingly developed with broad stakeholder consultation. Sociopolitical drivers of alternative futures in agriculture and agricultural knowledge, science and technology were identified in IAASTD throughout the developing world, like for example democratic decentralization, i.e., the transfer of political authority to lower levels of government as an important trend in political systems.

The Global IAASTD Report recognized among the options to enhance the impact of Agricultural Knowledge Science and Technology (AKST) on development and sustainability goals, innovations diffused through community institutions focused on agroecology as farming practices and technologies that are environmentally, socially and culturally sustainable (McIntyre et al. 2009, 411). Participatory agricultural and environmental projects that bring together local knowledge and western science were highlighted. The IAASTD Global report within the historical analysis of the effectiveness of agricultural knowledge, science and technology systems points towards the strong interdisciplinary collaboration in developing systematic approaches to agroecology carried out throughout the world in the 1980s, often led by NGOs (McIntyre et al. 2009, 71). The historical analysis within the IAASTD report highlights the emergence of civil society as a powerful force in the movement towards ecological pest management, in Northern as well as Southern countries (e.g., India, Thailand, Ecuador, Philippines, and Brazil). Civil Society Organizations (CSOs) and independent researchers - as well as FAO, the International Labour Organization (ILO), the World Health Organization (WHO) and some governments - have called for a rights-based approach to agricultural development, that explicitly recognizes agricultural workers' and rural communities' rights to good health and clean environments. Social movements such as the Brazilian Landless Workers' Movement and farmer-NGO-scientist partnerships such as the Latin American Scientific Society of Agroecology had a crucial role in contributing to the implementation of ecological pest management. However, scaling up to achieve widespread impact remained difficult in the absence of broader policy reforms (McIntyre et al. 2009, 105). Referenced in the IAASTD report was the work on agroecology since 1981 by Miguel Altieri and his research team at the University of California Berkeley, focused on the way in which biodiversity can contribute to the design of pest-stable agroecosystems. Much of the agroecological approach was conducted enhancing grassroots innovation capacities through inter-institutional partnerships devising integrated farming systems, emphasizing soil and water conservation, natural crop protection, achievement of soil fertility and stable yields through integration of trees, animals and crops (Altieri 2002; 1999; 1987).

During the process of elaboration of the report of the first Agrimonde foresight exercise (Paillard et al., 2011), the Annual Report submitted by the UN Special Rapporteur on the right to food, Olivier De Schutter, focused on Agroecology and the Right to Food, was taken into consideration. Drawing on an extensive review of the scientific literature, the Special Rapporteur identifies agroecology as "a mode of agricultural development which not only shows strong conceptual connections with the right to food, but has proven results for fast progress in the concretization of this human right for many vulnerable groups in various countries and environments" (A/HRC/16/49)[10]. The report argues that appropriate public policies can create an enabling environment for such sustainable modes of production. Among them the report prioritizes: the procurement of public goods in public spending rather than solely providing input subsidies, investing in forms of social organization that encourage partnerships, including farmer field schools and farmer movements innovation networks, empowering women, and creating a macro-economic enabling environment, including connecting sustainable farms to fair markets.

Agrimonde-Terra, the second CIRAD-INRA foresight exercise: embedding the sociotechnical imaginaries of a transition to agroecology

Launched in 2012, the context of Agrimonde-Terra was a time of increasing concern about the loss of biodiversity and ecosystems deterioration associated with the intensification of agriculture discussed in the MA. Diet-related chronic diseases related to nutritional deficiencies in developing countries were the subject of increased academic, policy and international attention (Lattre-Gasquet and Treyer 2016; WHO 2008).

In this context, the aim of Agrimonde-Terra was to build scenarios to explore the relationships between land-use and food security. Literature reviews on land use were carried out to identify the main direct and indirect causes of land use change. A brief analysis of civil society actors, policy actors, economic, business and research and innovation actors who influence changes in land use was also undertaken. Raising questions about the future of land-use patterns, this second CIRAD-INRA foresight exercise constituted an attempt to contribute to debates on land use trajectories addressing a series of questions including:

> "[W]hat impacts will population growth, urbanization, lifestyle changes, climate change and growing energy and meat demands have on land use to 2050? How can we ensure that land use will provide nutritional and food security for all to 2050? How should land, water and biodiversity be used to meet the demands of the planet's inhabitants in 2050? How can we ensure that the land will provide sustainable incomes for farmers and affordable prices for consumers? Which public policies should be implemented at different scales and in the different sectors?"
> (Lattre-Gasquet and Treyer 2016, 40)

A quantitative platform called GlobAgri was used for generating databases and biomass balance models customized for Agrimonde-Terra. The scenarios in this second foresight exercise were designed not only to explore a range of possible futures, but also to provide the public and decision makers with a tool that could be used to facilitate conversations about future land use at different scales, linking qualitative and quantitative approaches. In contrast with Agrimonde, designed as a platform for discussion and collective learning involving French researchers and stakeholders, Agrimonde-Terra was conceived as a forum for discussions among international researchers, policymakers and representatives of the civil society.

It proposed five exploratory scenarios. The first, '*Land use driven by metropolization*' linked the development of megacities with a nutrition transition led by global agri-food companies selling ultra-processed foods in a context of development through market forces, leading to the marginalizing of small farmers in areas disconnected from urban development. The second, '*Land use for regional food systems*' relates to the emergence of regional food systems based on family farming and their networking with medium-size cities. The third scenario, '*Land use for multi-active and* *mobile households*' relates to a global governance based on networks where family farms and co-operatives are major actors in land use and the development of non-farm employment with strong individual mobility between rural and urban areas and hybrid diets based on both traditional and modern value chains. The fourth scenario, '*Land use for food quality and healthy nutrition*' assumes a re-configuration of agricultural systems and a radical move towards healthy diets, driven by global cooperation and public policies in a context of climate change stabilization. The fifth scenario '*Land as commons for rural communities in a fragmented world*' assumes development based on small towns and rural communities, focusing on managing common resources and the transition to agroecology in agriculture in order to ensure food security in a context of recurrent crises (Mora 2018, 206-208).

Among the lessons learned from the comparison of Agrimonde and Agrimonde-Terra foresight exercises is the recognition that methods in future studies should be chosen in relation to the objectives. Agrimonde objectives were to inform research policy at national and global levels. The goal of Agrimonde-Terra was linking the foresight exercise to policy discussions. In this regard, a wider range of possible futures was taken into account to facilitate participation of members of civil society in the policy process.

In 2012, by the same time the Agrimonde-Terra foresight exercise was launched, a collaborative research network tracing public policy dynamics and rural development in Latin America and the Caribbean was initiated and supported by CIRAD. The Public Policies and Rural Development Network in Latin America (PP-AL) gathered over a hundred academic researchers and doctoral students from more than thirty teams and laboratories from ten countries in Latin America and the Caribbean to support the formulation and assessment of public policies for rural development through research and education. The partners of the PP-AL network meet to study the elaboration and implementation of agricultural, environmental and rural development policies in order to understand their dynamics and its effects, particularly in terms of transformations in the rural world and the challenges to understand and contribute to mitigate, alleviate and relieve inequalities. A significant feature of the PP-AL collaborative research network was the pluralist assessment of agricultural, environmental, social, territorial, rural development and cooperative public policies (Sabourin et al. 2017). Eric Sabourin, the CIRAD coordinator for the PP-AL collaborative research network is an anthropologist specialized in research focused on collective participatory governance frameworks involving common and public goods in peasant and rural organizations and their relation to public policies.

The PP-AL collaborative research network highlighted the transformative potential of multi-actor platforms for public policies elaboration, implementation and assessment. The knowledge encounters and dialogues unfolded by the PP-AL network, involving the interaction of scientific knowledge and local knowledge, allowed to trace the trajectory of agroecology in the Latin American and Caribbean region as a scientific discipline, as a set of agricultural practices and as a social movement and examine its role to support food and nutritional security as well as resilience and adaptation to climate change. The study carried out by the PP-AL network documented and analyzed the trajectories of Latin American initiatives and public policies supporting a transition to agroecology and its institutionalization. Among the aims and objectives identified by the PP-AL network, the health of soils, ecosystems and human beings are emphasized and conceptualized as interdependent.

The study on public policy and family farming in Latin America undertaken by the PP-AL network concluded that in order to promote agricultural sustainability, confronting biodiversity loss, socioenvironmental and climate change challenges, governments were negotiating with civil society transversal sets of instruments in the form of policy-mix.

AgMIP's transdisciplinary approach to climate change and agricultural systems modeling: embedding the sociotechnical imaginaries of "climate-smart agriculture"

AgMIP's transdisciplinary approach to climate change and agricultural systems modeling: Stakeholder Engagement and Decision Support embedding the sociotechnical imaginaries of "climate-smart agriculture"

The concept of Climate-Smart Agriculture (CSA) was officially presented at The Hague Conference on Agriculture, Food Security and Climate Change in 2010 through the paper "Climate-Smart Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation" (FAO 2010). CSA was defined in this FAO paper as "agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes GHG (mitigation), and enhances achievement of national food security and development goals" (FAO 2010, ii). The same year, the Agricultural Model Intercomparison and Improvement Project (AgMIP) was launched and became a member of the Global Alliance for Climate-Smart Agriculture[11] which was also launched in 2010.

This section follows the global circulation of the ideas, visions and aspirations about scientific and technological futures initially associated to the concept of CSA, examining how it both embeds and is embedded in institutions, instruments, discourses, economic, material and social infrastructures. This section characterizes AgMIP focusing on the work of its research methods team on Representative Agricultural Pathways (RAPs); in particular, on its development of scenarios for regional integrated assessment of climate change impacts, vulnerability, and adaptation (Valdivia et al. 2021; 2015; Rosenzweig et al. 2021; Rosenzweig and Hillel 2015; Hillel and Rosenzweig 2012).

For over a decade, since 2010, the Agricultural Model Intercomparison and Improvement Project (AgMIP)[12] community of researchers has been joining efforts with the aim of advancing methods for improving predictions on the future performance of agricultural systems. At the end of 2022, thirty teams integrate AgMIP[13]. Twelve teams are dedicated to *research methods*, like for example: the AgMIP Data Interoperability Group [AgDIG], the Aggregation and Scaling group, the Calibration group, the Coordinated Global and Regional Assessments [CGRA], the Global Economics team [GlobEcon], and the Representative Agricultural Pathways [RAPs] group. Another twelve teams focus on *biophysical modeling* such as: the Bioenergy group, the Fruits and Vegetables group, the Maize team, the Potato team, the Rice team, the Soybean team. The third cluster dedicated to *cross-cutting topics* is integrated by ten teams, among them: the Pests and Diseases group [PeDiMIP], the Soils and Crop Rotation group, the Water Resources group, and the Stakeholder Engagement and Decision Support group.

The first phase of AgMIP was carried out by four teams: Climate, Crop Modeling, Economics and Information Technology (Rosenzweig et al. 2015, 5). The AgMIP Information Technology (IT) team - in charge of developing the IT infrastructure for AgMIP projects to allow access to shared data, models and results - enables the compilation, archiving and exchange of data and information for the AgMIP research community and stakeholders. This team explores state-of-the-art information and communication technologies relevant to improve agricultural modeling oriented to organize the online dissemination of AgMIP data and outputs (Rosenzweig et al. 2015, 12-13).

National and international agronomic research organizations (such as CGIAR), governments (United Kingdom, USA, European Commission), and companies (Monsanto) provided funding and in-kind support (Cornilleau 2019, 67). Headquartered at the Center for Climate Systems Research, Earth Institute, Columbia University, this transdisciplinary modeling global research network, since its first phase, built relationships with multiple groups of stakeholders, including national and regional agricultural planners and policymakers with the goal of linking research and development. The rationale for this approach was to contribute to a stronger integration of science and stakeholder-based knowledge that "will enable priority setting and support decision-making processes guided by a joint strategy development" (Valdivia et al. 2021, 47). The selection of regional research teams involved a criterion for early stakeholder engagement including representatives from agricultural ministries, farmer organizations, national and regional adaptation planners, crop breeders, non-governmental organizations, and extension agents. Each year, Global Workshops anchored this community, facilitating collaboration to set agendas and design protocols for AgMIP activities. Stakeholders participated also in AgMIPs' national, and regional workshops contributing to the dissemination of project information (Rosenzweig et al. 2015, 16-17).

Research findings of the AgMIP stakeholder-driven project on Regional Integrated Assessment of climate change and farming systems in Africa and South Asia were recently published (Rosenzweig et al. 2021). This work presents the methods and results of a multi-year project funded by the United Kingdom's Department for International Development (UK DFID).

Prior to 2018, among AgMIPs' principal investigators stands out Cynthia Rosenzweig, the co-founder of AgMIP, a senior research scientist at Columbia University's Center for Climate Systems Research, and a senior research scientist at NASA Goddard Institute for Space Studies - where she heads the Climate Impacts Group. In 2022, she was awarded the World Food Prize[14].

Prior to co-founding AgMIP, Rosenzweig was in 2007 a coordinating lead author on assessment of observed changes and responses in natural and managed systems for the IPCC Working Group II Fourth Assessment Report. In 2019 she was a coordinating and lead author of the Food Security Chapter, part of the Special Report on Climate Change and Land for the IPCC Working Group II on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.

After 2018, AgMIPs' Steering Council[15] - in charge of providing grounding knowledge of cutting-edge research, development, partnerships, private-sector engagement and funding priorities of AgMIP - was co-chaired by Ghassem R. Asrar, Senior Vice President for Science at Universities Space Research Association in Maryland, USA, and Jean-Francois Soussana, Vice-Chair for International Affairs of the *Institut national de la recherche agronomique* (INRA), a French public research institute dedicated to agricultural science that since 2020 merged with the *Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture* (IRSTEA) to create the *Institut national de recherche pour l'agriculture, l'alimentation et l'environnement* (INRAE). Even though INRA became INRAE, Soussana is still in charge of international research policy. Besides, he is since 1998 member of the Working Group II of IPCC and was Lead Author for the Third, Fourth, Fifth, and Sixth Assessment Reports as well as for the Special Report on

Land and Climate Change by IPCC Working Groups I, II and III together. He has developed novel experimental and mathematical modelling approaches to the impacts of global change on agriculture, soils, biodiversity, carbon and nitrogen cycles and greenhouse gas emissions[16].

AgMIP's methodological approach to climate change and agricultural systems modeling. Representative Agricultural Pathways (RAPs) and Scenarios: Increasing credibility of assessments and consistency for the advancement of science

Over the last sixty years, agricultural systems modeling was developed and use for decision making support at various scales (Jones et al. 2017a). Decision Support Systems (DSSs) software packages that make use of models for farm financial planning and general crop and land management have been used at farm level decision making by farmers and farm advisors. Besides, agricultural system models are increasingly being used to inform research and development investment decisions and inform public policy at landscape, national and global scales.

Over the same period there has also been an increase in demands for addressing new questions by modeling moving beyond more efficient production for higher profitability to include exploration of sustainable solutions that address multiple goals and challenges like climate change, volatile energy prices, limitations of land, water and other natural resources as well as models of nutritional quality of food for policy analyses. Reviews focusing on the capabilities and limitations of agricultural systems models indicate that major advances are needed 'to address more complex issues and achieve food security during the next century' (Jones et al. 2017b, 284).

The creation of AgMIP in 2010 was associated with the recognition of the need for better coordination among the agricultural modeling community. In contrast with previous climate change assessments assuming the same socio-economic conditions in the future as today, AgMIP developed Representative Agricultural Pathways (RAPs) as part of its Regional Integrated Assessment (RIA) method for modeling and projecting agricultural systems in the present and future. 'RAPs deliver scenarios about possible future states of the world in which climate change might happen.' (Valdivia et al. 2021, 48).

Consistency as a challenge associated to the credibility of assessments was considered not only in relation to intercomparison, improvement, and synthesis of model results across studies at various scales (local, national, regional and global) but also across disciplines (Valdivia et al. 2015). In this regard, pathways were developed as multi-dimensional concepts that incorporate a set of dimensions for assessment. A key feature of pathways is a set of corresponding narratives that contain the rationale to interpret the pathway logic, facilitating the use of pathways for developing sector and region-specific versions for different types of research. For example, the development of Representative greenhouse gas Concentration Pathways (RCPs) and Shared Socio-economic Pathways (SSPs) designed as independent dimensions may be used to present a scenario matrix to reflect that a particular concentration's trajectory could correspond to various socio-economic conditions. Scenarios can be designed to represent future worlds with either low or high emissions combined with various levels of economic activity and types of mitigation and adaptation capabilities and policies (Valdivia et al. 2015).

AgMIP's global and regional integrated assessment modeling framework represents different geographical scales, considering various biophysical processes from Representative greenhouse gas Concentration Pathways (RCPs) and Global Climate Models (GCM) to water, soil and pest processes. The AgMIP modeling framework combines the RCP and the GCM with the socio-economic pathway, examining agricultural productivity, costs and policy, taking into account at the local scale farm size, input cost, among other dimensions. The impact models of AgMIP's agricultural assessment modeling framework generate outcomes for global, multi-country regions, by country or subregions of a country. Both agricultural production system models (including crop and livestock simulation models) and agricultural economic models at regional and subregional scales include variables in more detail like agriculture specific inputs - such as labor, machinery, seeds, fertilizers, irrigation water and fuels- and agriculture specific policy parameters – like for example domestic output, input taxes or subsidies. Among the impact models, a major limitation of most biophysical production system models is that they are not capable of simulating the effects of pests and diseases on crops or livestock (Valdivia et al. 2015).

AgMIP's assessment approach to climate impact, vulnerability and adaptation is based on the development of Representative Regional Agricultural Pathways (RAPs) and scenarios in a manner consistent with global pathways and scenarios. Prior to this development, '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' (Valdivia et al. 2015, 103). AgMIP's experience in developing RAPs involved an integrative process of collaboration among disciplines to transcend what can be achieved by individual disciplines or by simply passing information from one disciplinary researcher or group to another.

AgMIP's transdisciplinary approach to ensure logical consistency between model components on a given spatial and temporal scale as well as across scales portrays five possible RAPs corresponding to combinations of low and high economic development and more or less sustainable biophysical conditions. RAP 1 is the case of adverse synergies resulting in low outcomes when persistently high population growth led to both poverty and environmental degradation. RAP 2 represents a middle ground balance of economic and sustainability indicators. RAP 3 is the case of win-win synergies representing sustainable high growth. RAP 4 correspond to policies that achieve environmental protection by severely restricting economic activity. RAP 5 corresponds to the continuation of present trends where productivity growth continues at a high level by continuing to exploit natural resources in an unsustainable manner. This RAP is not a feasible option 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.

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 a collaboration with National and International institutions in Sub-Saharan Africa and South Asia. Among the challenges identified during the process of RAP development were (i) the identification of key indicators; (ii) data availability: it was challenging to find reliable data; (iii) reaching agreements about the direction and magnitude of changes of indicators; (iv) interaction with stakeholders: explaining the RAP frame.

The AgMIP regional research team in Sub-Saharan Africa and South Asia during the first phase of the DFID-funded project produced a series of RAPs for farming systems following a "Business as Usual" pathway. In the second DFID funded phase, a Green RAP was developed presenting a future driven by sustainability goals and a Grey RAP representing a future that is driven by economic growth without considering sustainability (Valdivia et al. 2021).

Discussion and Final Reflections

The case studies of agro-climate foresight, modeling and scenario development that this article explored in the preceding sections shed light on the challenges involved in the interdisciplinary development of anticipatory knowledge practices that "turn the future into an object of scientific enquiry and political intervention" (Aykut et al. 2019) to facilitate thinking about the possible consequences of different courses of action.

The making and use of global models and scenarios as well as their methodological choices raise questions about the actors supporting, funding and participating (or being excluded from) their elaboration and evaluation, the matters of concern and dimensions of the problem taken into account, the assumptions and sets of knowledge on which they are based. Tracing the emergence of visions of desirable futures within the modeling/scenario development/foresight Agrimonde and AgMIP networks, their embeddedness in global assessments and the process of embedding these visions into institutions, material and social infrastructures allowed us to explore the emergence and extension of two sociotechnical imaginaries: 'transition to agroecology' and 'climate smart agriculture'.

The analysis of the two case studies in agro-climate foresight approached in this article was previously engaged drawing on a framework that articulated economic sociology and science and technology studies pointing towards the politics of knowledge (Dorin and Joly 2020). From this perspective, and conceptualizing knowledge and politics as co-produced (Jasanoff 2004), a distinction was introduced to contrast mainstream models of world agriculture like AgMIP, built and used as 'evidence-based predictions', from models and scenarios built and used as learning machines (Berkhout et al. 2002) such as Agrimonde and Agrimonde-Terra.

Models of world agriculture conceptualized as 'evidence-based predictions' in which the symbolic power of mathematics are mobilized to build credibility and enable communication across epistemic boundaries, since the 1960s were dominated by economists. From the 1990s, agricultural models were integrated in earth models used by the IPCC. The integration of biophysics and economics framed world agriculture not only in terms of food balance and trade but also in relation to adaptation and mitigation of climate change (Dorin and Joly 2020, 3). The case of AgMIP is discussed as illustrative of mainstream approaches mainly representing the industrial production systems promoted by public policies since the Green Revolution. Drawing on a framework that articulated economic sociology and science and technology studies, the analysis pointed towards the invisibilization of alternatives to global large-scale industrial agriculture in mainstream models.

In contrast, the modeler of Agribiom was prevented from creating a black box because the Agribiom model was designed as a learning machine, to be a "companion to expert interactions and discussions" and "using modeling and scenarios to construct desired futures and test their consistency and viability" (Dorin and Joly 2020, 5-6).

Another previous engagement with the two case studies discussed in this article, considered the actors who develop and use these models through the lens of field theory, contributing to a dialogue between neo-institutionalist field theory and its Bourdieusian version, pointing towards the promotion of technology-intensive agriculture over agroecology in mainstream models (Cornilleau 2019). Through interviews of modelers, situating their models in relation to others and analyses of reports, Cornilleau's study focused on the mechanisms of the competition between different models of world agriculture. Addressing not only the modeling field per se, but also its interaction with the academic field and the field of global governance, the structure of the modeling field was analyzed in terms of the relative positions of modeling organizations according to the accumulated scientific and political 'capital' of their model evaluated through the reputation of each model in both the academic and global governance fields.

In this article, the analysis of the Agrimonde and AgMIP modeling/ scenario development/ foresight interdisciplinary communities, identified and traced the processes of embedding the sociotechnical imaginaries of a 'transition to agroecology' in the case of the Agrimonde Project and the 'climate smart agriculture' sociotechnical imaginary in the case of AgMIP. This analytical work focused on food security as a multiscalar public issue unfolding in a series of global assessments. In this scenario, mainstream models - supported by governments and transnational corporations - that for a long time dominated the field becoming a reference tool for providing foresight on food security, were put under scrutiny. During the IAASTD process, the IAASTD Advisory Committee asked to reflect on the possible futures for agriculture, on the basis of scenarios created with IMPACT. This choice followed the Millennium Ecosystems Assessment and the IPCC, which used IMPACT to represent world agriculture. Tensions arose in the debates at IAASTD on scenario development criticizing the presentation of political assumptions as scientific findings, raising questions about how collective visions are produced within science-policy interfaces and categorizing mainstream models as elitist tools, hindering inclusive deliberations on the future of agriculture (Scoones 2009). "In the end, the IMPACT model was not used to prepare the scenarios of the IAASTD, which became mostly qualitative" (Cornilleau 2019, 65).

Within the IAASTD process, the historical analysis of the effectiveness of Agricultural Knowledge, Science and Technology (AKST) Systems in promoting innovation highlighted the strong interdisciplinary collaboration throughout the world in the 1980s, often led by non-governmental organizations (NGOs), in developing systemic approaches to agroecology. These interdisciplinary collaboration efforts positioned the agricultural sciences at the interface of the natural and social sciences. The drivers for these more inclusive and integrated science practices were associated with the emergence of gender studies and women in agricultural development projects (McIntyre et al. 2009, 70). Besides, FAO's Food and Hunger reports showed the persistence of widespread hunger, rural unemployment and food insecurity. Studies of land degradation, water pollution and loss of flora or fauna species associated these sustainability issues with narrow technological interventions (Repetto 1985; Repetto et al. 1989; Repetto 1990). Critical reflection extended across scientific disciplines "on the governance of agricultural science and the accountability of science as a source of innovation not only for "success" but also for "failure" in agricultural development" (McIntyre et al. 2009, 71). Economic analysis based on empirical case studies of public policy from Asia (India, Sri Lanka, etc.) and Latin America (Mexico and Colombia) related to the 'green revolution'[17] suggested systematic bias in government policies, resulting in greater income inequality (Griffin 1979). However, the translation of the understanding of the social and ecological sustainability complex and complementary perspectives into action faced strong barriers within the scientific community and from market specialization and the dominance of formal economic drivers over social and ecological sustainability concerns (McIntyre et al. 2009, 70-71).

The sociotechnical imaginary of a transition to agroecology was circulated in Northern as well as in Southern countries like India, Thailand, Ecuador, Philippines and Brazil by civil society organizations, independent researchers as well as FAO, ILO, WHO and some governments. Social movements such as the Brazilian Landless Workers Movement contributed to embedding the transition to agroecology in educational institutions (Tarlau 2019; Meek and Tarlau 2016). Farmer-NGO-scientist partnerships like the Latin American Scientific Society of Agroecology (SO-

CLA by its Spanish acronym)[18] contributed to the extension of agroecological approaches to pest management. Yet, in the absence of broader policy reforms, scaling up agroecology to achieve widespread impact remains a pending issue (McIntyre et al. 2009, 105).

In this regard, the CIRAD-INRA Agrimonde Project can be understood as a movement towards embedding and extending the transition to agroecology as a sociotechnical imaginary in research institutions, in modeling/scenario development and foresight and in science-policy interfaces. Research undertaken by CIRAD prioritized the study of family farming[19] (Sabourin et al. 2014), and research on the emergence of public policy in favor of agroecology in the Latin American and Caribbean region (Sabourin et al. 2017). This movement converged with: the UN declaration of the International Year of Family Farming (2014), to recognize the importance of family farming for improving food security, the declaration of the UN Decade of Family Farming 2019-2028, and the UN Declaration on the Rights of Peasants and Other People Working in Rural Areas (2018)[20]. This resolution adopted by the Human Rights Council in 2018 declared that "states shall take measures aimed at the conservation and sustainable use of land and other natural resources through agroecology and ensure the conditions for the regeneration of biological and other natural capacities and cycles" (Article 17, 7). These movements can be considered as the institutionalization of previous Civil Society Organizations and NGOs efforts confronting foresight approaches predicting the inevitable demise of the peasantry.

The term climate smart agriculture "was widely adopted before the development of a formal conceptual frame and tools to implement the approach", this explains why "there has been considerable variation in meanings applied to the term, which also contributed to controversies" (Lipper and Zilberman 2018, 13). Since its official launch in 2010, the 'climate smart agriculture' sociotechnical imaginary has been reshaped through inputs and interactions of multiple stakeholders involved in developing and implementing the concept. In 2012, following the Conference on Sustainable Development (Rio+20), a high profile gathering where agriculture and hunger eradication have taken their rightful place as one of the top priorities on the international agenda, the FAO report on the State of Food and Agriculture (SOFA) focused on increasing the levels and the quality of investment in agriculture. In this edition, promoting large scale public and private investment in agriculture the sociotechnical imaginary of 'climate smart agriculture' was circulated, linking climate finance to the climate-smart agriculture approach (FAO 2012, 55). The 2014 SOFA report acknowledges the concerns raised by the use of CSA by a wide range of stakeholders applying various definitions. In this regard, CSA was presented as an approach that "does not constitute a recommendation for any specific technological solution to address climate change; rather, the approach provides tools for assessing which technologies will deliver the desired results in different locations" (FAO 2014, 40). In succeeding editions of the SOFA report, the climate smart sociotechnical imaginary was highlighted, recommending that more climate finance needs to flow from public sources as well as customized financial products for the development of climate-smart food production systems (FAO 2016, xvi). CSA is also circulated in the 2020 SOFA report edition on overcoming water challenges in agriculture, associating this sociotechnical imaginary to climate-smart irrigation agriculture as an important option for adaptation to climate change (FAO 2020, 67).

Since the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (AR5), the notion of maladaptation (Barnett and O'Neill 2010) was introduced, pointing towards institutional decision-making favoring one group over another. Barnett and O'Neill define maladaptation as: "action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups" (Barnett and O'Neill 2010, 211).

> Actions taken in response to climate change can aggravate existing significant inequalities or grievances over resources (Marino and Ribot, 2012), limit access to land and other resources required to maintain livelihoods, or otherwise undermine critical aspects of human security (Bumpus and Liverman, 2008; Fairhead et al., 2012). Maladaptation or greenhouse gas mitigation efforts at odds with local priorities and property rights may increase the risk of conflict in populations, particularly where institutions governing access to property are weak, or favor one group over another (Barnett and O'Neill, 2010; Butler and Gates, 2012; McEvoy and Wilder, 2012). Research on the rapid expansion of biofuels production connects land grabbing, land dispossession, and social conflict (Borras et al., 2010; Dauverge and Neville, 2010; Molony and Smith, 2010; Vermeulen and Cotula, 2010). One study has identified possible links between increased biofuels production, food price spikes, and social instability such as riots (Johnstone and Mazo, 2011).
> IPCC 2014 WGII AR5 Part A, 773

The dimensions of maladaptation identified by Barnett and O'Neill include among others, "actions that, relative to alternatives: increase emissions of greenhouse gases, disproportionately burden the most vulnerable, have high opportunity costs, reduce incentives to adapt, and set paths that limit the choices available to future generations" (Barnett and O'Neill 2010, 211).

This IPCC report warns that "Maladaptation may occur if the true potential of an option or a technology is unduly over-emphasized, making it over-rated" (IPCC 2014 WGII AR5 Part A, 858). This IPCC report illustrates this warning pointing towards "agricultural policies that promote the growing of high-yielding crop varieties through subsidies with the objective of boosting production and increasing revenues may achieve these objectives in the short term, but will also reduce agro-biodiversity and increase exposure and vulnerability of mono-crops to climate change and finally undermine the adaptive capacity of farmers in the long term" (IPCC 2014 WGII AR5 Part A, 858).

Maladaptation risks are acknowledged since this IPCC report as a cause of increasing concern, conceptualized as an intervention in one location or sector that could increase the vulnerability of another location or sector, or increase the vulnerability of the target group to future climate change. "The definition of maladaptation used in AR5 has changed subtly to recognize that maladaptation arises not only from inadvertent badly planned adaptation actions, but also from deliberate decisions where wider considerations place greater emphasis on short-term outcomes ahead of longer-term threats, or that discount, or fail to consider, the full range of interactions arising from the planned actions (IPCC 2014 WGII AR5 Part A, 837).

Within the discussion of the maladaptation framework, participatory approaches to assessment are identified as an opportunity to avoid maladaptation (IPCC 2014 WGII AR5 Part A, 851). Adaptation interventions largely emphasizing short-term risk management over long-term transformative strategic planning to reduce long-term risk create the potential for maladaptation (IPCC 2014 WGII AR5 Part A, 924).

Some options and policies that may result in trade-offs, including social impacts, ecosystem functions and services damage and water depletion, are increasingly problematized at the intersection of debates of Working Groups I, II and III at the IPCC Climate Change and Land report

(IPCC 2019, 28). A forest plantation that sequesters carbon for mitigation can also reduce water availability to downstream populations and heighten their vulnerability to drought (IPCC 2019, 103). Some adaptation options can become maladaptive due to their environmental impacts, such as irrigation causing soil salinization or over extraction leading to ground-water depletion (IPCC 2019, 20).

> During a drought from 2007–2009 in California, farmers adapted by using more groundwater, thereby depleting groundwater elevation by 15 meters. This volume of groundwater depletion is unsustainable environmentally and also emits GHG emissions during the pumping (Christian-Smith et al. 2015). Despite the three years of drought, the agricultural sector performed financially well, due to the groundwater use and crop insurance payments. Drought compensation programmes through crop insurance policies may reduce the incentive to shift to lower water-use crops, thereby perpetuating the maladaptive situation.
> IPCC 2019, 734

Climate justice and rights-based approaches are recognized as key principles within mitigation and adaptation strategies and projects (IPCC WGII 2022, 1175). Participatory approaches are increasingly taken into account. These approaches engage the concerns and involvement of a broader range of interest groups and stakeholders, including a variety of co-generative strategies like for example qualitative scenario or adaptation pathway development. In this way, goals and objectives, knowledge and strategy implementation and evaluation can be decided collaboratively between practitioners, policymaking, local groups and scientists (IPCC WGII 2022, 2576).

Considering the challenges of maladaptation and the potential of participatory approaches[21] to prevent them, addressing participatory approaches to agro-climate foresight in research and research policy emerges as a promising opportunity. To complement the analytical trajectory followed in this article to analyze agro-climate foresight/scenario development and modeling efforts, considering the potential of rights-based approaches to confront maladaptation risks, the articulation of the food democracy framework (Collart Dutilleul 2014; 2013) seems promising for future work.

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Notes

[1]Sheila Heimenrath is a lawyer and a student at the Master in Law and Economy of Climate Change at the Latin American Faculty of Social Sciences (FLACSO) Argentina. Her thesis project is focused on research policies on agriculture and climate change in Argentina and France. Her research interests include sociotechnical transitions, regulatory and institutional challenges related to the public problematization of land uses, food security and food democracy.

[2]http://foresight-platform.eu/

[3]INRA (The Institut National de la recherche agronomique) founded in 1946, merged in 2020 with IRSTEA (Institut national de recherche en sciences et technologies pour l'environnement et l'agriculture) to form INRAE (Institut national de recherche pour l'agriculture, l'alimentation et l'environnement).

[4]https://www.fao.org/gacsa/members/en/

[5]http://foresight-platform.eu/

[6]The EFMN, aimed at understanding foresight practice, promoted processes of thinking about the future in a variety of domains, such as natural sciences, medical sciences, engineering and technology, agricultural sciences, social sciences, and the humanities (Giesecke et al. 2009; 2008).

[7]https://www.millenniumassessment.org/en/index.html

[8]The variables of the Agrimonde system include (1) *Global context* (population, urbanization and rural exodus, economic growth, advances in knowledge, income distribution, agricultural commodity prices); (2) *International regulations* (International political relations, organization of international trade, international agreements on climate, international agreements on biodiversity, governance and management of sanitary risks, governance and management of marine resources, North-South capital flows); (3) *Dynamics of agricultural production* (production areas, investments in farming, investments in infrastructures and public goods, social forms of production, production techniques, processing agroindustry: organization and production technologies); (4) *Dynamics of biomass consumption* (consumption habits and diets, society's awareness of sanitary issues, society's awareness of environmental issues, consumption of biomass for energy production, consumption of biomass for the production of industrial goods); (5) *Actors' strategies, States' strategies, Private actors' strategies* (Agricultural policies, sanitary and nutrition policies, energy policies, environmental policies, role of professional agricultural organizations, strategies of multinational firms, role of NGOs); (6) *Knowledge and technologies in the field of food and agriculture* (Investments in public and private research and development, objectives of innovations, intellectual property system for living organisms, orientation of agricultural research, farmers training, organization and actors of innovation and its diffusion); (7) *Sustainable development, Natural resources, Social equity* (Biodiversity conservation, greenhouse gas emissions and climate, Soil fertility, Water availability and quality, Satisfaction of essential needs: food, health, employment, education, Quality of life: dwellings, culture, social relations) (Paillard et al. 2014, 5).

[9]See chapters 1 and 2 in Paillard et al. (2014).

[10]https://www.ohchr.org/en/special-procedures/sr-food/annual-thematic-reports

[11]https://www.fao.org/gacsa/members/en/

[12]See: Agmip.org

[13]https://agmip.org/research-2/agmip-teams/

[14]The World Food Prize was founded by Norman Borlaug, the 1970 Nobel Peace Prize Laureate for agricultural research, within the International Maize and Wheat Improvement Center (CIMMYT for its Spanish acronym), associated to the Green Revolution. On the Green Revolution, a package of technologies of cultivation introduced since the mid-twentieth century including hybridized seeds associated with chemical fertilizers and pesticides, and irrigation infrastructure within industrial monoculture approaches see Pingali 2012; Glaeser 2011; Kloppenburg 1988; Griffin 1979.

[15]https://agmip.org/steering-council/

[16]https://agmip.org/steering-council/

[17]The green revolution technoscientific package included the adoption of new varieties of seeds, synthetic fertilizers, pesticides, combined with the improvement of irrigation and new agricultural practices. For the discussion and controversies associated to the green revolution see Kloppenburg (2004), Patel (2013), Picado Umaña (2021).

[18]https://soclaglobal.com/

[19]On the state of family farming in the World see Graeub et al. (2016).

[20]https://digitallibrary.un.org/record/1650694?ln=en

[21] On participatory foresight for food systems change see Hebinck et al. (2018).