CLIMATE CHANGE, TRANSFORMATIVE ADAPTATION OPTIONS, MULTISCALE POLYCENTRIC GOVERNANCE, AND SOCIAL WELFARE:

TOWARDS AN EMPIRICAL EVALUATION IN THE CONTEXT OF OUM ER RBIA BASIN, MOROCCO

15.12.2022

Colombo, Sri Lanka

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CGIAR
INITIATIVE ON
Climate Resilience

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Suggested Citation

Saleth, R.M., Amarasinghe U., Amarnath G., AA El Mekki., Brouziyne, Y. 2022. Climate Change, Transformative Adaptation Options, Multiscale Polycentric Governance, And Social Welfare: Towards An Empirical Evaluation in the Context Of Oum Er Rbia Basin, Morocco. CGIAR Climate Resilience.

Acknowledgments

This work was carried out with support from the CGIAR Initiative on Climate Resilience, ClimBeR. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund.

Table of Contents

1. Context and Setting

Agriculture is the main source of food, income, and livelihood for millions of people across the world. But this sector is also the most vulnerable to climate change with significant welfare implications and spillover effects even on other sectors having critical input-output linkages with agriculture. Since agriculture is where land, water, and climate converge, it provides the most appropriate context not only for understanding the impacts of climate change but also for evaluating how these impacts can be managed through transformative adaptation options such as climate-resilient interventions and coping strategies, including targeted climate-centered investments.

Grassroots level impacts of climate change are often evaluated in terms of key dimensions of social welfare such as food, income, and livelihood. The evaluation of these welfare dimensions is usually based on static or time-invariant indicators or variables. But when the evaluation is performed in terms of dynamic pathways of impact, as characterized by chains of both sequentially and simultaneously interacting variables, it is possible to bring together both *non-institutional variables* (cover not only the variables capturing physical, economic, environmental, and technological aspects but also those representing various transformative adaptation options) as well as *institutional variables* within a unified analytical framework.

Current literature is focused more on evaluating how effective are the transformative adaptation options in coping with the impacts of climate change, but not that much on exploring whether relevant institutions and infrastructures exist and how effective are they in underpinning the effectiveness of the adaptive options. Besides, with an exclusive focus on the roles of the easy-to-handle non-institutional variables, current research either ignores institutional and infrastructural variables or treats them only marginally without actually recognizing their intrinsic operational linkages with non-institutional variables. Such an insufficient treatment of institutional variables is due to the presumed difficulties in conceptualizing and operationalizing them and the tendency to assume all institutions are in place and working properly.

Overcoming the limitations of current literature, the research proposed here aims to develop an empirically applicable methodology that can bring together within a unified analytical framework all relevant institutional and non-institutional variables. These variables can characterize various impact pathways mediating across climate change, water, agriculture, and social welfare. As the impact pathways are defined by functionally related and structurally embedded sets of institutional and non-institutional variables, the analytical framework can also be translated into a mathematical model capable of being empirically evaluated using parametric and/or perception-based data on the chains of variables behind different impact pathways. Empirical results from the application of the methodology can provide both theoretical and practical insights into the relative impacts and performance enhancing roles of various institutional elements that together characterize multiscale and polycentric governance (MPG) structure in any given setting.

2. Objectives and Scope

The proposed research forms part of Work Package #4 (WP4) of CGIAR Research Program: Building Systemic Resilience against Climate Variability and Extremes (ClimBeR). It will support the achievement of the overarching objective of WP4, i.e., setting up a bottom-up polycentric governance framework for multiscale transformative adaptation and targeted climate investments. It will also have analytical and empirical contributions to other components of WP4 such as ClimaAdapt-Gov dashboard and AWARE platform. It will also have implicit contributions to parts of WP2 and WP3, particularly in the form of evaluating the impacts of variables capturing transformative adaptation options and their performance linkages with institutional variables or governance elements.

The overall objective of the proposed research is to develop an empirically applicable methodology for capturing and evaluating the critical linkages between the relative success of transformative adaptation options and their relative effectiveness as determined by the underlying institutions and infrastructures at various scales and contexts. The specific objectives of the proposed research are as follows:

1) Set the stage by developing a conceptual and operational understanding of MPG structure based on the intrinsic functional connections among institutions, infrastructures, and governance using definitions, terminologies, and stylized facts from institutional economics;
2) Identify and describe the empirical context developing and evaluating the analytical framework and methodology;
3) Develop and explain an analytical framework that will capture the specific roles of institutions and infrastructures in different impact pathways as defined by the chains of interacting variables—both institutional and non-institutional—through which climate change impacts and mediating effects of transformative adaptation options are conveyed to water and agriculture sectors and transmitted ultimately onto social welfare;
4) Define a set of institutional and non-institutional variables and mathematically translate the analytical framework into an empirically applicable model that captures all major impact pathways and their underlying chains of variables;
5) Discuss the issues and options involved in the empirical application of the model in suitable location and context;
6) Apply the model empirically in select context to evaluate the relative roles of various institutional elements of MPG structure in enhancing the effectiveness of various transformative adaptation options in coping with the impacts of climate change on agriculture at various scales and contexts.
7) Use model results to: (a) to trace and rank different institutional and non-institutional variables in terms of their relative performance and impact and (b) scan and identify weak links and transmission gaps both within and across impact pathways and variable chains for diagnostic and correctional purpose.

8) And, finally, conclude by indicating the outputs, timelines, and resource needs for completing the core components of proposal research: (a) development and finalization of analytical framework and methodology, (b) data collection for empirical application in select context(s), and (c) estimation, data analysis, drafting, and final documentation.

As to its scope, the proposed research deals mainly with the grassroots level impacts of climate change largely within the sectoral setting of agriculture, though other related sectors are treated both implicitly (e.g., land in terms of area cultivated) and explicitly (e.g., water and agro-and non-farm sectors). While both the macro and micro effects are considered, the coverage is limited only to some of the major impact pathways. Similarly, although candidate institutions and infrastructures considered are a few, they do cover important institutional and infrastructural elements related to agricultural, rural, water, and trade sectors. The same can also be said about transformative options being considered. The methodology will cover both the individual and joint roles of institutional and infrastructural elements of MPG structure in enhancing the effectiveness and climate resilience contributions of different transformative adaptation options.

3. Unbundling and Operationalizing MPG Structure

To unbundle and operationalize the MPG structure in line with the objectives and scope of WP4 in general and those of the proposed research in particular, it is necessary to understand certain intrinsic functional connections among institutions, infrastructures, and governance across scales and contexts. For this purpose, we need to rely on the following definitions, terminologies, and stylized facts from institutional economics:

(1) Since institutions are entities defined interactively by legal, policy, and organizational components, these components and their constituent elements together form the *institutional structure*. Likewise, since institutions are embedded and functioning in a given physical, socio-economic, political, and technological setting, they form part the *institutional environment.*

(2) Institutions and infrastructures are functionally inter-related because many institutions often perform infrastructural roles (e.g., role of agricultural extension system as input distribution network) and many infrastructures perform institutional roles (e.g., role of water conveyance networks in water rights allocation).

(3) Institutions, infrastructures, and governance are both conceptually and operationally connections. Since institutions and infrastructures are the tools (as both the software and hardware) of governance, the latter is treated essentially as the outcome of the former, but with a sharp focus on process involving, *inter alia*, decision-making, participation, and accountability. In this sense, institutions and governance can be used interchangeably because one cannot exist without the other.

(4) While the process perspective of governance has received wider research attention, the institutional and infrastructural perspective of governance has not received the level of research attention that it really deserves. The latter, for instance, is very important from empirical and diagnostic perspectives, particularly in understanding and evaluating the relative roles of underlying institutional and infrastructural elements that together determine overall governance effectiveness and performance, particularly in the context of mediating the climate resilient impacts of various transformative adaptation options across scales and contexts.

(5) Just like institutions, governance systems are also hierarchical and contextual in nature. As such, they obviously vary by region, sector, and context, displaying multiscale and polycentric characteristics. But regardless of such variations, they do display intricate functional linkages and joint impacts flowing across scales and contexts. Therefore, governance, by its very nature, is inherently MPG in character.

(6) And, finally, Paralleling the way institutions are unbundled, regardless of its scales and contexts, governance can also be unbundled at three levels: (a) *governance structure* can be distinguished from the *governance environment*. The latter covers the overall physical, social, economic, political, and technological milieu within which the former is embedded and operating. (b) governance structure can be unbundled into its three core *institutional components*, i.e., laws, policies, and organizations.[1] And, (c) each of these three institutional components can, in turn, be unbundled to identify the respective constituent *institutional elements*.

With the facts noted above, it is now possible to connect the dots among institutions, infrastructures, and governance can be connected across scales and context, particularly from the institutional perspective of MPG structure. It is also clear now what are the institutional elements that together the

[1] The institutional/governance components are contextual in the sense that in agricultural context, the components will be: agricultural laws, agricultural policies, and agricultural organizations. Similarly, for water context, they will be: water laws, water policies, and water administration and so on.

MPG characterize the governance structure and what roles they play in within mediating context of climate change, transformative options, MPG structure and social welfare.

3.1 Conceptual Foundation of the Study

Figure 1 provides a conceptual foundation underlying the analytical framework and evaluation methodology for the study. It is based on contrasting three scenarios: (1) evaluating the impact of climate change on the overall goal, which we have taken here as rural welfare; (2) evaluating the impact of climate change on rural welfare, taking into account the role of transformative adaptive options (TAOs) and (3) evaluating the impact of climate change on rural welfare, taking into account not only the role of TAOs but also the mediating effects of multi-scale poly-centric governance (MPG) structure (i.e., institutional factors operating across scales and sectors). The analytical framework and evaluation methodology to be developed and empirically applied in this study is obviously based on the more realistic scenario 3.

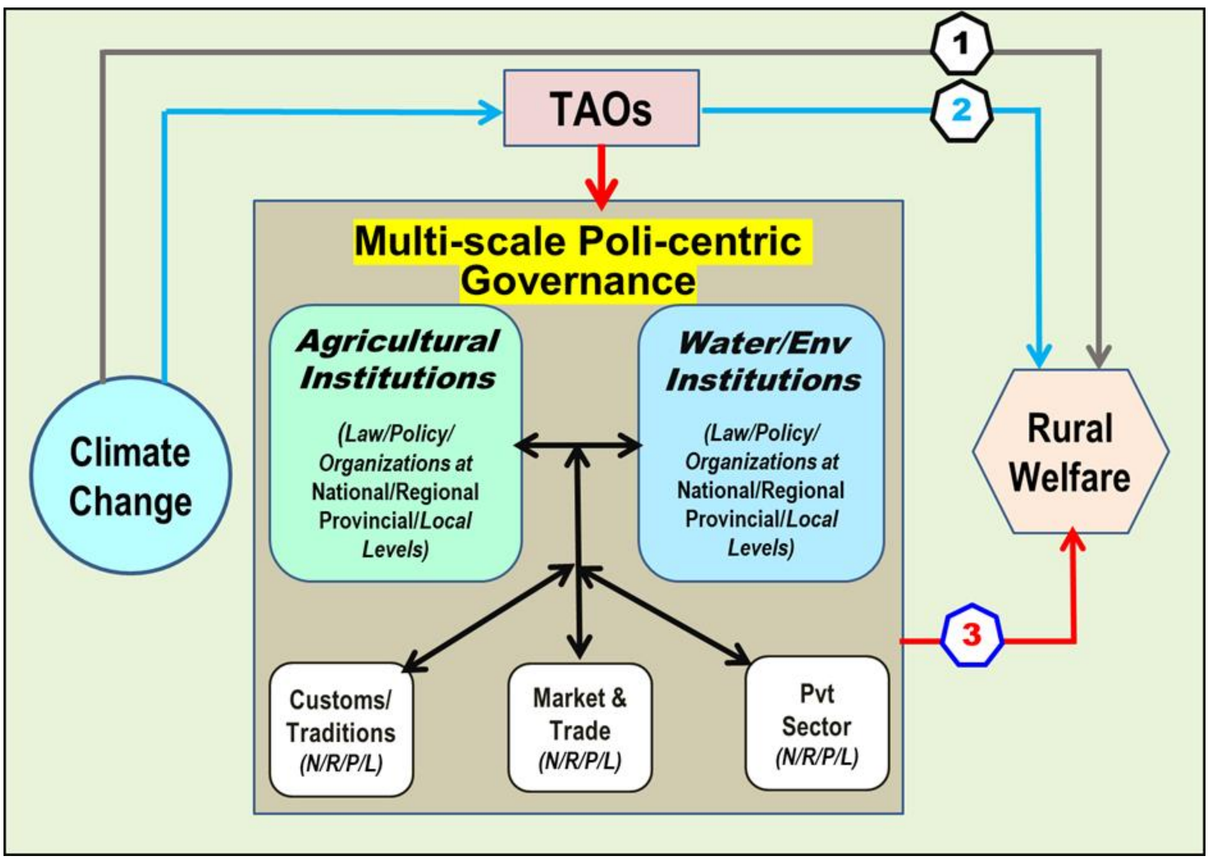

Figure 1: Climate Change-TAOs-MPG-Welfare Interaction: Three Stylized Scenarios

On the economic front, Morocco is a relatively liberal market-based economy, following a policy of privatization and liberalization since 1993. With a Gross Domestic Product (GDP) of $112.8 billion, Morocco remains the fifth largest economy in Africa and wields significant influence both within Africa and the Arab world (World Bank, 2021).

Politically, Morocco is a unitary semi-constitutional monarchy with an elected parliament with two chambers. The executive branch is led by the King and the Prime Minister, while legislative power is vested with the parliament and Judicial power rests with the Constitutional Court. The King holds vast executive and legislative powers, though the 2011 constitutional reforms has enhanced the executive roles of the Prime Minister have been enlarged. Administratively, Morocco is divided into 12 regions, covering 62 provinces and 13 prefectures. The Oum Er Rbia Basin covers either fully or part of three regions, i.e., Beni Mellal-Khenifra, Casablanca-Settat, and Marrakesh-Safi. The study region Beni Mellal-Khenifra comprises of five provinces, .e., Azilal, Beni Mellal, Fquih Ben Salah, Khenifra, and Khouribga. Beni Mellal Province is selected as the focus area for this study.

From a geographic perspective, the country has three geographic regions: the Atlantic coastal lowlands, the mountainous interior covering Atlas and Rif Mountain ranges, and arid and desert regions of the east and south. With diverse topographies ranging from mountains and plateaus, to plains, oasis and Saharan dunes, Morocco displays varying climatic conditions with extreme rainfall variability across space and over time. Climatically, 93 percent of Morocco is characterized by arid and semi-arid conditions (USAID, 2010). Irregular rain patterns, cold spells, and heat waves and drought conditions severely affect agriculture.

4. Empirical Setting: Oum Er Rbia Basin, Morocco

The analytical and methodological works proposed in this study are to be evaluated in the particular empirical context of the Oum Er Rbia Basin of the Kingdome of Morocco. A brief description of the study region and is useful will not only provide a strong background for the study but also enable an understanding of the rationale and justification their choice.

4.1 Morocco: Polity, Economy, and Geography

To being with, Morocco, officially the Kingdom of Morocco, is the westernmost country in the Maghreb region of North Africa (see Figure 2) with a total area of about 71 million ha (mha). Morocco has a population of 37.9 million, growing at an annual rate of 1.2 percent. It is projected to reach 66.4 million by 2030 and 72.8 million by 2050. Urban population constitutes 62 percent at percent, but expected to reach 69% and 77% by 2030 and 2050 respectively (World Bank, 2021).

Figure 2: Kingdom of Morocco and Its River Basins

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4.2 Morocco: Agriculture

Although service and industry sectors, including mining, dominate GDP with a 50 and 25 percent share respectively, agricultural sector, with just a just 14 percent share, is strategically very important. Moroccan agriculture is the largest employer, accounting 43% of all employment and 78% of rural employment.

Agriculture production is based on an arable area of 8.7 mha, supporting diverse cropping and mixed farming systems. While 16 percent of this area with irrigation can support food and other high-value crops, production in over 80 percent of the area depends on highly variable and uncertain rain. In terms of crop pattern, about 43 percent of the area is devoted to cereals, 7 percent to plantation crops (olives, almonds, citrus, grapes, dates, etc.), 3% to pulses, 2 percent each to forage, vegetables, and industrial crops like sugar beets, sugar cane, cotton and oilseeds, and the remaining 41% to fallow.

Given the climatic and rainfall conditions of Morocco, irrigation plays a key role both in the level and stability of production, employment, and incomes in rural areas. There is a strong correlation between annual agricultural output and annual rainfall. Due to this correlation and the strong economic weight of the agricultural sector, each rainfall deficit impacts the whole economy of the country. Despite representing slightly over 16 percent of the cultivated land, irrigated agriculture contributes to about half of the agriculture GDP, 75 percent of agricultural exports, and 15 percent of overall merchandise exports. The country has 1.46 million ha of permanently irrigated land, 682,600 ha of which are part of nine Large Scale Irrigation (LSI) perimeters operated by nine public agricultural development agencies (ORMVA) (World Bank, 2015).

Agriculture in Morocco is characterized by a dichotomy of traditional and market-oriented agriculture, which also coincides to some extent with a dichotomy of irrigated and rainfed agriculture. Market agriculture is concentrated mostly in irrigated areas focused mainly on high-value crops for export and industrial production. In contrast, traditional sector involving small farms in rainfed areas is focused predominantly in cereal, legume, and livestock production. Rural population that represents about 34 percent of total population composed of small subsistent farmers whose production depends almost entirely on rainfall. Moroccan agriculture operates through a mixed and integrated crop/livestock system, representing the main source of income for the majority of rural households. Most arable land and rangeland are located in areas receiving less than 400 mm of rainfall, where cereals and small ruminants mainly sheep are integral components of an extensive dryland production system.

4.3 Morocco: Food Security and Poverty

The agricultural sector suffers from deep structural problems. It remains very sensitive to climatic fluctuations and to the pressures of trade liberalization. The reform of the sector is not only essential in itself but is unavoidable because of the deadline for the liberalization of agricultural trade with the European Union. The issue of what is effectively a water subsidy to promote the cultivation of cereals in unfavorable areas will need to be tackled. Under normal rainfall conditions, Morocco produces enough food for domestic consumption except for grains, sugar, coffee and tea. More than 40% of Morocco's consumption of grains and flour is imported from the United States and France. However, Morocco is almost self-sufficient in meat production and trying to become self-sufficient in dairy production as well. Morocco is one of the few Arab countries that has the potential to achieve self-sufficiency in food production. But achieving this potential requires the achievement of climate resilience.

From an overall perspective, Morocco has made tremendous progress in the areas of quality of life and socio-economic fronts. While the country has made strides in poverty reduction, its economic vulnerability still remains a major challenge. Although absolute poverty has reduced from 15% to 9% during 2001–2007, still 27% of the population, especially in rural areas, is considered to be poor, vulnerable, or near poor (USAID, 2010; World Bank 2009a; World Bank 2009b). Since 70 percent of this poor live in rural areas, they remain the source of massive rural exodus towards the cities or the EU. From the perspective of food security, during 2019-21, 3.1 million people are considered to be severely food insecure and another 8.6 million people are considered to be moderately food insecure.

4.4 Morocco: Water Sector

With a long-term average precipitation of 346 mm/year, the total renewable water resources of Morocco is estimated to be 29 billion cubic meter (bcum)/year. Of this ultimate potential, the total resources that can be actually exploited under current technical and economic conditions is estimated to be only at 22 bcum/year—18 bcum of surface water and 4 bcum of groundwater. At this level, water per capita for Morocco would be just 730 cum, which is far below the United Nations' water stress threshold, i.e., 1,000 cum. The overall water deficit is estimated at around 2 bcum (MEMEE, 2011; Plan Bleu, 2011; World Bank 2015).

Notably, there is also a spatial concentration of the exploited water resources as more than 50 percent of which are distributed in the Central and Northern regions of the country. Of the 12 basins, only three basins, i.e., Loukkos, Sebou and Oum Er Rbia, account for 71.5 percent total surface water resources in the country. In contrast, underground resources are relatively better distributed over the territory. Of the 96 aquifers listed, 21 are deep aquifers and 75 are shallow ones. The largest aquifer systems cover a total area of nearly 80,000 km^2, or about 10 percent of the territory (MEMEE, 2009).

Although Morocco has the capacity to develop irrigation to the extent of 2.5 mha, the area currently equipped with full irrigation is only 1.46 mha (FAO, 2015). In terms of irrigation methods, flood irrigation dominates with 71 percent of this area, followed by drip (20 percent) and Springler (9 percent) systems. In terms of irrigation types, major irrigation (those managed by ORMVAs) accounts for 47 percent, small and medium irrigation for 23 percent, and private irrigation for 30 Percent.

From a supply-demand perspective, Morocco has developed over the years a vast water infrastructure system to store, transfer, divert, and extract water resource from different sources. This includes 135 large dams with a combined storage capacity of 17 bcum, another 14 large dams with a storage capacity of 2.6 bcum, hundreds of small dams with a combined storage of 0.1 bcum, 13 water transfer structures with a total length of 785 km with a capacity to transport more than 2.7 bcum, an vast network of wells, boreholes, and springs that can mobilize nearly 4 bcum of groundwater, and traditional water diversion structures, particularly in mountain regions, with an average diversion capacity of 1.7 bcum (MEMEE, 2011; CES, 2014).

Considering the damaging effects of siltation on dam storage capacity, year-to-year variations in rainfall, and other uncertainties, the currently build water infrastructure system can be expected to provide an average annual supply of around 13 bcum (Plan Bleu, 2011). But average annual water demand amounts to 14.7 bcum. Of this demand, 13.2 bcum (90 percent) is meeting irrigation needs and the rest for meeting drinking (1.1 bcum) and industrial and environmental (0.4 bcum) needs (Plan Bleu, 2011). In view of the demand-supply gap, there is a water deficit of around 4 bcum, of which around 1 bcum is met by groundwater water overexploitation (CSEC, 2014).

Since irrigation water needs are not fully satisfied, agricultural production is reduced, particularly in ORMVA regions. Of the 12 basins, water deficit is particularly severe in the Oum Er Rbia, where it is estimated to be nearly 1.2 bcum 00 million m³ (Plan Bleu, 2011). The consequence of such a water deficit is a serious overexploitation of aquifers, leading a lowering of water table even to the extent of almost 2 m/year (CSEC, 2014). The problem and consequences of water deficit is going to get further complicated with the further growth in water demand and the potential effects on water supply from already visible impacts of climate change.

4.5 Morocco: Impacts of Climatic Change on Water and Agriculture

Obviously, Morocco is highly vulnerable to climate change and variability. The country is regularly facing extended periods of dry spells, drought episodes, and wet periods with a regime of uncertain and irregular precipitation, causing flash floods at times. Global climate change is likely to complicate more to the existing problems.

Climate variability and change are putting increased pressure on the climate-sensitive water and agricultural sector, which, in turn, affects the overall economic performance of Morocco. For instance, 2016 drought, the worst in past 30 years, reduced cereal yields by 70 percent and has significantly slowed the overall economic growth (USAID (2016). The predominant climate concern for Morocco relates to its impact on the limited and declining water resources. While water demand is expected to increase due to population growth, economic expansion, and rising irrigation needs, water resources are projected to decline due to frequent and recurrent drought conditions, reduced storages from dam siltation, and physical limits for future water development.

Water per capita has declined by almost 60 percent since 1960 due to non-climate stressors such as population growth, urbanization, economic development, and irrigation expansion. At the same time, there has been a 20-percent reduction in overall water resources in the last 30 years due essentially to natural and climate stressors such as rising temperatures, increased evaporation, erratic rainfall, and siltation. Supply reduction is also expected to increase over time. For example, in the particular context of two major dams, i.e., Hassan Addahkhil and Idriss I, both are critical water sources in the country, supply is projected to decline by 7 to 40 percent by 2080.

Climate change that negatively affects water supply is likely to raise the demand for irrigation, which already accounts for 90 percent of available water, though covers only 16 percent of farm area. Since 84 percent of crop production (particularly barley and wheat) rainfed, Moroccan agriculture is highly vulnerable to increased rainfall variability. For instance, the drought of 2016 has reduced the harvested yields by 70 percent as compared to 2015. The hotter and drier conditions associated with the same has also increased crop water requirements up to 12 percent, raising the demand for irrigation and adding more stress to the already limited water resources.

Climate variability is expected to add pressures on water resources in Morocco. Projections indicate 10%-20% decreases in precipitation across the country, with the most severe in the Saharan region by 2100. Additionally, climate change will reduce snowpack in the Atlas Mountains. This puts pressure on water resources, already stressed by other sources such as population expansion, urban growth, industry, and tourism. Furthermore, many coastal aquifers will increasingly become stressed because of coastal salinization. There are several studies that have evaluated the impacts of climate change on the water and agricultural sectors of Morocco from different perspectives and contexts (Schilling, et al., 2012; Tramblay, et al, 2014; El Baki, et al., 2021; Echakraoui, Z., et. al., 2018).

4.6 Morocco: Major Initiatives to Enhance Climate Resilience

In recent years, the Government of Morocco has taken several innovative initiatives and large programs and actions to enhance the climate resilience of its agricultural and water sectors by addressing some of the major technical, institutional and structural issues. These initiatives and programs focus on improving agricultural and water productivity levels by expansion of irrigated land, development of water-delivery infrastructure, and modernization of the agricultural and water sectors. The most important among these initiatives and programs include Green Morocco Plan [Plan Maroc Vert (PMV)] covering the period of 2010-2020, National Irrigation Water Saving Program (PNEEI) promoted since 2009-10, and Green Generation Plan (2020-30).

The PMV is a broad strategy with a larger mandate for climate change such as producing half of the country's energy by renewables, removing fossil fuel subsidy, and generating green employment by 2030. But this strategy also aims to double agricultural value-added and create 1.5 million jobs by 2020, thus transforming the sector into a stable source of growth, competitiveness, and broad-based economic development. Reflecting the dualistic nature of Moroccan agriculture, this strategy has two pillars—one targeting commercial farmers and the other targeting small farmers in marginal areas.

PNEEI has promoted the shift from flood irrigation to drip irrigation with a view to save water and improve water productivity and use efficiency. This program aims to shift of 555,090 ha to drip irrigation—337,150 ha of individual conversion and 217,940 ha of collective conversion of family farms in major schemes. This process is supported with up to 100 percent subsidy for the adoption of drip and micro-sprinkler irrigation, and up to 70 percent subsidy for sprinkler irrigation. Since PNEEI's launch in 2008, the adoption of drip irrigation has been proceeding at a fast pace in privately developed irrigation areas, with over 200,000 ha completed (60 percent of the 2020 target). In LSI perimeters, conversion is ongoing on 57,000 ha only, due to the need for prior investments in the irrigation networks. In this way, PNEEI contribute to the modernization of irrigation delivery system. In terms of water saving, the area equipped with drip irrigation systems has expanded significantly to reach 542,000 ha by 2020 as against just 128,000 ha in 2008.

The Green Generation Plan being implemented since 2020, promotes several key social and organizational options covering both human and sustainability elements. Under the human element, the Plan aims to create and strengthen rural middle class, diversify rural jobs, and promote new production organizations involving young rural entrepreneurs. Sustainability element covers climate resilience and agricultural sustainability. This Plan also provides for crop and employment insurance and stipend for poor farmers.

These initiatives, especially PMV, have generated major benefits. For instance, since PMV's launch in 2008, production has increased by 45 percent, agricultural exports have risen by 18 percent. Since agricultural GDP has increased annually by 5.25% against 3.8% for the other sectors, there has been an additional value added to the extent of 47 billion MAD. Also, exports of agricultural products increased by 117% from 15 to 33 billion MAD. On the social level, PMV has also enabled the creation of 342,000 additional jobs. Furthermore, the number of working days per year and per worker has increased from 110 days/year to 140 days/year due to the expansion of cultivated areas, crop diversification, and enhanced production.

Under PMV, agricultural value added has increased through two processes: agricultural aggregation and Public-Private Partnership (PPP) around the leased lands from the state and tribal communities. With the dedicated incentive system established under Law No: 04-12m 63 aggregation projects, covering a total area of 177,000 ha, were implemented for the benefit of 55,000 farmers, 80% of whom are small farmers owning less than 5 hectares. Under PPP involving leased of state-owned land, 1,575 projects were set up covering an area of nearly 112,000 ha and projected investment of 22.3 billion MAD and generating 63,000 jobs. Notably, 720 of projects were allocated to small farmers and entrepreneurs in the agricultural sector. More importantly, the plantations carried out under pillar II, despite their young ages, would have contributed carbon sequestration in the order of 1.9 million tons equivalent of CO2.

From a climate resilience perspective, the initiatives and programs have promoted several transformative adaptation options (TAOs) within the agricultural and water sectors. These most important among these options include:

a. Shifting of Crop Pattern to Tree Crops,
b. Shifting from Flood and Sprinkler to Drip Irrigation Systems,
c. Contract Farming/Value Chain Developments,
d. Public-Private Partnership (PPP) in Agricultural Development (Land Leasing/Corporate Farming), and
e. Zero Tillage Farming Technology in Rainfed Regions

It will be very interesting to evaluate how some of these TAOs can improve climate resilience, especially when they are supported by an effective governance structure at various scales.

4.7 The Study Basin: Oum Er Rbia Basin

The sample basin selected for this study is Oum Er Rbia Basin (see Figure 2). Oum Er Rbia is the second largest River in Morocco after the Sebou River (with an average water throughput of 105 m3/s). This basin has six major dams (including Al Massira, the second largest dam in Morocco with 2.65 bcum storage capacity) and five minor dams. The combined storage capacity of these dams is estimated to be 5 bcum. But due to drought condition and siltation, the actual storage 2022 is just 7.6% of their capacity (even as against 18.5% in 2021).

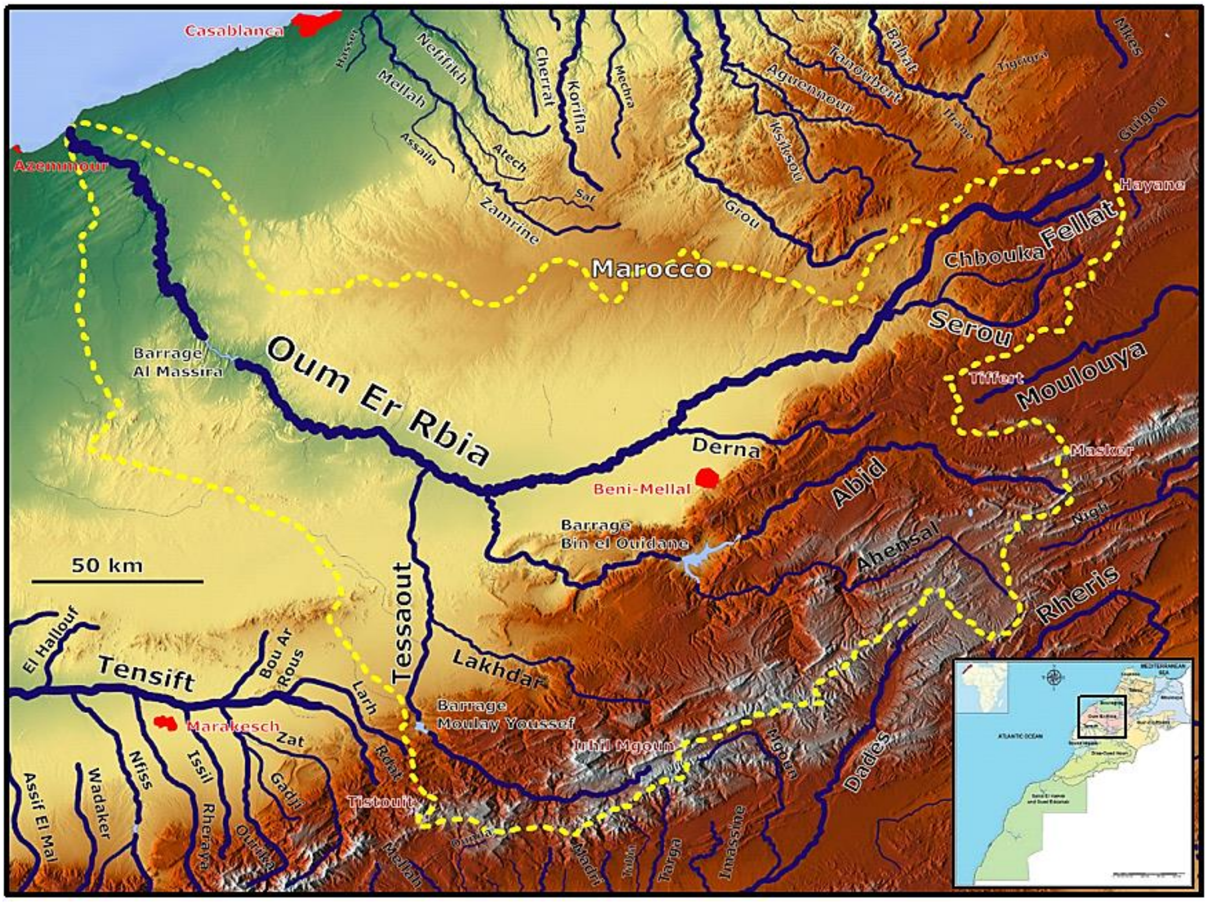


Figure 3: Oum Er Rbia River Basin, Morocco

Oum Er Rbia is very important for agricultural production. This basin accounts for 33 percent of the total harvested area in the country. Major Crops grown include Wheat and Barley (largely under rainfed conditions) and Maize, Olives, Almonds, Sugar Beets, Oranges, Dates, etc. (mostly under irrigated conditions). This basin has the top share in the harvested area of most crops, except wheat in which it has only the second highest share after the Sebou basin. Oum Er Rbia basin also accounts for 33 percent (0.48 mha) of the total irrigated area (1.46 mha) in country (FAO, 2013). In terms of water footprint (both green and blue water use), Oum Er Rbia basin dominates with a 7.7 bcum, representing over third of the total water foot print of the country (23.5 bcum).

This basin is highly susceptible to climate change impacts, including high frequency and intensity of droughts. Based on historical data, it has been estimated that over the years, Oum Er Rbia basin has experienced a 20% reduction in rainfall and 40 to 49% decline in annual flow.

5. Analytical Framework: Impact Pathways and Variable Chains

Let us develop an analytical framework for capturing the major impact pathways between climate change, TAOs, MPG structure, and social welfare in the particular context of the agricultural and water sectors of Oum Er Rbia Basin of Morocco. This setting will be more specialized to fit the economic and institutional realities and TAOs of identified study area. The analytical framework and evaluation methodology to be presented here is based on the original works developed by Saleth, Dinar and Frisbie (2011).

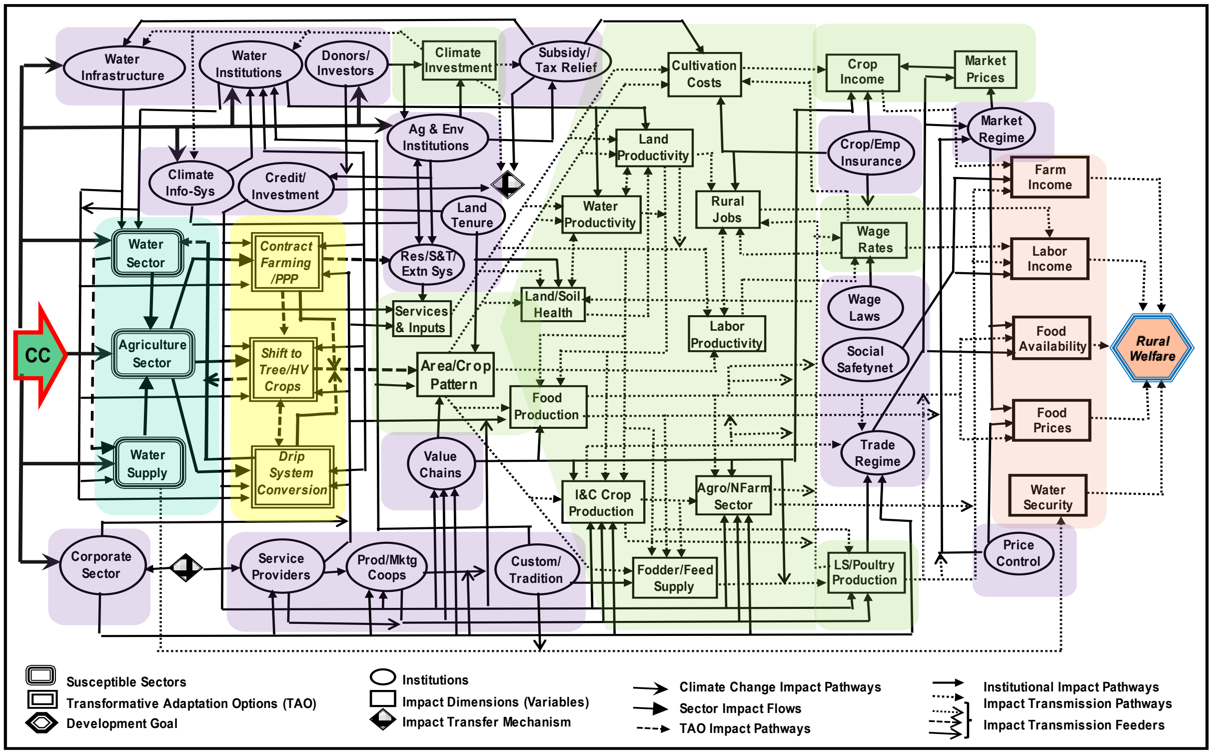
As can be seen, the impacts of climate change are transmitted through a variety of impact pathways, which are characterized by various chains of institutional and non-institutional variables. In such an impact transmission process, the institutional variables can either magnify or moderate the initial impacts of independent and intermediate variables. It is these roles that will determine the effectiveness and performance MPG structure on the impact mediating process. Before proceeding further, it is useful to note a few key points related to the reading and interpreting Figure 4.

(1) For reading and interpreting Figure 4, one needs to proceed from left to right and, at each stage, move down from top to bottom. Anyhow, the arrows (both solid and dotted) show the direction of flow.

(2) Figure 4 is somewhat abstract and aggregative. It does not cover all the aspects of the intricate and multifarious linkages among climate change, water, agriculture, institutions, infrastructures, and social welfare. However, Figure 4 does capture the most important and policy-wise more relevant linkages. This is essentially for analytical simplification and sharpen the focus on key linkages.

(3) Although climate change is included in a generic format. its specific formats that can be considered for evaluation include various combinations of temperature and rainfall along with their impacts in terms of dry climate, floods, waterlogging, droughts and crop failures, etc. Obviously, the exact nature of the impacts on agriculture depends on which climate

change scenario is going to prevail in a given context. In this sense, the analytical framework in Figure 4 can be used to perform sensitivity analysis of different climate scenarios.



(4) For reading and interpreting Figure 4, one needs to proceed from left to right and, at each stage, move down from top to bottom. Anyhow, the arrows (both solid and dotted) show the direction of flow.

FIGURE 4: CLIMATE CHANGE-TRANSFORMATIVE ADAPTATION OPTIONS-MPG STRUCTURE-WELFARE INTERACTION: ANALYTICS AND PATHWAYS

(5) Figure 4 is somewhat abstract and aggregative. It does not cover all the aspects of the intricate and multifarious linkages among climate change, water, agriculture, institutions, infrastructures, and social welfare. However, Figure 4 does capture the most important and policy-wise more relevant linkages. This is essentially for analytical simplification and sharpen the focus on key linkages.

(6) Although climate change is included in a generic format, its specific formats may include various combinations of temperature and rainfall along with their impacts in terms of floods,

waterlogging, droughts, and crop failures, etc. Obviously, the exact impacts of climate on agriculture depends on which climate scenario is expected to prevail in a given context. In this sense, the analytical framework in Figure 4 can be used to perform sensitivity analysis of different climate scenarios.

(7) Similarly, agriculture can be represented in a variety of forms such as changes in cultivated area, crop pattern, and cropping intensity. Each of these forms can be represented by one or more variables. Notably cultivated area implicitly brings land resource into the framework. Also, climate adaptations can involve suitable adjustments in these three variables as well as the addition of other resources, inputs, and investments that go with such adjustments.

(8) When considering the impact of climate change on agriculture, water assumes central role. This is because water—both natural and applied—remains not only critical for agricultural productivity but also the main medium through which most of the impact of climate change will be felt on agriculture in particular and society in general.

(9) For distinctions, the initial variable (climate change) and the ultimate impact variable (social welfare) are placed in Figure 4 within hexagons. The immediate variables on which climate impact is felt first are in placed small rounded rectangles, the intermediate impact variables are placed in rectangles, and the institutional and infrastructural variables are placed in ovals.[2]

(10) And, finally, in Figure 4 the transformative adaptation options are placed both in half ovals with bold dashed lines (science and technology and adaptive management) as well as in elongated ovals (water infrastructures and water institutions). Notably, the four transformative options represent package or multiple sets of variables, each of which captures different adaptation options.[3]

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[2] The institutional variables are also distinguished by placing them within rounded rectangles with dotted lines. While most of the impact variables are dependent (endogenous) on the effects of other variables, most of the institutional variables are independent (exogenous) in nature.

[3] For instance, science and technology and adaptive management include options such as improved crop varieties, water technologies, precision farming, etc. Similarly, adaptive management can include multiple cropping, crop diversification, deficit irrigation, zero-tillage, etc. Likewise, water infrastructures include components such as storage systems, distribution networks, flood protection mechanisms, water harvesting structures, etc. In a similar way, water institutions cover water-related legal, policy, and organization elements. But specific institutional mechanisms can include water rights, water markets, water banks, water pricing, user organizations, etc.

With these points, it is straight forward to interpret and understand the analytical framework specified in Figure 4. When suitable sets of variables are defined to capture various institutional and non-institutional variables, all the layers of impact pathways evident in Figure 4 can be formally translated into a mathematical model involving a system of inter-linked equations.

6. Modeling Institutional Roles in Climate Change-Agriculture-Welfare Interface

For developing a mathematical representation of the analytical framework evident in Figure 4, the following set of institutional, non-institutional, and impact variables need to be developed:

Main Impact Variable

CLCIMPACT = Climate Change Impact

Overall Development Goal

RUWELFARE = Rural Wellbeing

Sectors/Sub-Sector

WATRAVAIL = Water Resource Availability *(Water Sector)*

AGPERFORM = Agricultural Sector Performance *(Agricultural Sector)*

WATRSUPLY = Water Supply *(Water for People, Animals, and Industries)*

Transformative Adaptive Options *(TAOs)*

CONFAMPPP = Contract Farming and Public-Private Partnership

CROPSHIFT = Shift to Tree and High-Value Crops

DCONVIMOD = Drip Conversion and Irrigation Modernization

Institutional Variables *(Elements of Multi-scale Poly-centric Governance)*

LANDTENUR = Land Tenure *(Farm Size, Land Leasing, etc.)*

WATRINSTN = Water Institutions

WATRINFRA = Water Infrastructures

AGENINSTN = Agricultural and Environmental Institutions

DONINVSTR = International Donors and Investors

CLIMINSYS = Climate Information and Decision Support System

AGCRINSTN = Agricultural Credit and Investment Institutions

STAXPOLCY = Subsidy and Tax Relief Policies

ARESEXSYS= Agricultural Science/Technology, Research, Extension System

CUSTINSTN = Customary and Traditional Institutions

CORPSECTR = Corporate Sector Agencies/Players

RSPROVIDR = Rural Service Providers

APMKTCOOP = Agricultural Production and Marketing Cooperatives

AVALCHAIN = Agricultural Value Chains

CREMINSUR = Crop and Employment Insurance

AGWAGELAW = Agricultural Wage Laws and Regulations

SNETPOLCY = Rural Social Safetynet Policies

ATRDREGIM = Agricultural Trade Regime

AMKTREGIM = Agricultural Market Regime

AFPRPOLCY = Agricultural and Food Price Regulation Policies

Impact Dimensions *(Impact Transmission Variables)*

CULTIAREA = Cultivated or Cropped Area

CROPATERN = Cropping Pattern

AGINSUPLY = Agricultural Service and Input Supply

CLIMINVST= Climate Investment Level

LANDSQLTY = Land Quality and Soil Health

LANDPRODY = Land Productivity

WATRPRODY = Water Productivity

LABRPRODY = Labor Productivity

FOODPRODN = Food Production

INDCPRODN = Industrial and Commercial Crop Production

FEEDSUPLY = Fodder and Feed Supply

LSPSIZCOM = Livestock and Poultry Population Size and Composition

LIVSPRODN = Livestock and Poultry Production

AGNFSECTR = Agro-industries and Non-farm Sector

RURALJOBS = Rural Jobs

RURALWAGE = Rural Wage Rates

CULTICOST= Cultivation Costs

AMKTPRICE = Market Prices of Farm Products

CROPINCOM = Income only from Crop Enterprises

FARMINCOM = Farm Income from agriculture, livestock, and other sources

LABRINCOM = Labour Income from wage, non-farm, and other sources

FOODAVAIL = Food Availability

FOODPRICE = Food Prices

WATRSECUR = Water Security for People, Animals, and Nature

At this stage, a few key aspects and features of the defined variables requires noting. First, variable CCHANGE will represent drought, if higher temperature is coupled with deficit rainfall, or floods, if reverse is the case. Second, list includes variables of both qualitative (e.g., AGPOLCY, ENPOLCY, ATPOLCY, etc.) quantitative (e.g., AOUTPUT, FINCOME, APRICES, CULCOST, etc.) in nature. Although information on this latter set of variables can be collected in quantitative units, this needs to done only in an *ex-ante*, involving degree of subjective and qualitative considerations. Third, the calculation of values for some variables (e.g., WATINFR, WATINST, SCITECH, AMANAGE, etc.) has to be based on appropriate summation or aggregation of the values of sub-variables, representing different elements or options in each case.[4]

Given the defined set of variables, the analytical framework specified in Figure 4 can be mathematically converted into the following set of 42 equations.

AGENINSTN = f_1 (CLCIMPACT, *DONINVSTR*) .... [1]

CLIMINVST = f_2 (CLCIMPACT, *AGENINSTN, DONINVSTR*) .... [2]

CLIMINSYS = f_3 (CLCIMPACT, CLIMINVST) .... [3]

ARESEXSYS = f_4 (*AGENINSTN,* CONFAMPPP, *CLIMINSYS*) .... [4]

STAXPOLCY = f_5 (CLIMINVST, *AGENINSTN*) .... [5]

AGCRINSTN = f_6 (*AGENINSTN, DONINVSTR*) .... [6]

CORPSECTR = f_7 (CLCIMPACT, CLIMINVST, *AGCRINSTN, STAXPOLCY*) .... [7]

RSPROVIDR = f_8 (CLIMINVST, *AGCRINSTN, STAXPOLCY*, *CORPSECTR*) .... [8]

APMKTCOOP = f_9 (*AGCRINSTN*, *RSPROVIDR*) .... [9]

AVALCHAIN = f_{10} (*AGCRINSTN, APMKTCOOP, RSPROVIDR, CORPSECTR*) .... [10]

CULTIAREA = f_{11} (CONFAMPPP, CROPSHIFT, DCONVIMOD, *LANDTENUR,*
AVALCHAIN, CUSTINSTN) .... [11]

CROPATERN = f_{12} (CULTIAREA, CONFAMPPP, CROPSHIFT, DCONVIMOD, *LANDTENUR,*
AVALCHAIN, CUSTINSTN) .... [12]

LANDPRODY = f_{13} (CULTIAREA, CROPATERN, WATRPRODY, AGINSUPLY,
LANDSQLTY,*WATRINSTN*) .... [13]

WATRPRODY = f_{14} (CULTIAREA, CROPATERN, LANDPRODY, AGINSUPLY,
LANDSQLTY, *WATRINSTN*) .... [14]

LABRPRODY = f_{15} (CULTIAREA, CROPATERN, LANDPRODY, RURALJOBS,
AGINSUPLY) .... [15]

FOODPRODN = f_{16} (CULTIAREA, CROPATERN, AGINSUPLY, LANDPRODY, WATRPRODY,

[4] For instance, WATINFR includes infrastructure components such as storage systems, distribution networks, flood protection mechanisms, water harvesting structures, and water infiltration points. Similarly, WATINST covers institutional elements such as water rights system, water markets, water banks, water pricing, and user organizations.

AGCRINSTN, APMKTCOOP, RSPROVIDR, CORPSECTR, AVALCHAIN) .... [16]

INDCPRODN = ***f17*** (CULTIAREA, CROPATERN, AGINSUPLY, LANDPRODY, WATRPRODY, *AGCRINSTN, APMKTCOOP, RSPROVIDR, CORPSECTR, AVALCHAIN*) .... [17]

FEEDSUPLY = ***f18*** (CULTIAREA, CROPATERN, FOODPRODN, INDCPRODN, AGINSUPLY, *CUSTINSTN*)... [18]

LIVSPRODN = ***f19*** (LSPSIZCOM, FEEDSUPLY, AGINSUPLY, *AGCRINSTN*, *APMKTCOOP, RSPROVIDR, AVALCHAIN, CORPSECTR)* .... [19]

AGNFSECTR = ***f20*** (FOODPRODN, INDCPRODN, *AVALCHAIN*, *AGCRINSTN*, *APMKTCOOP, RSPROVIDR, CORPSECTR*) .... [20]

ATRDREGIM = ***f21*** (FOODPRODN, LIVSPRODN, INDCPRODN, *CORPSECTR*) .... [21]

AMKTREGIM = ***f22*** (FOODPRODN, LIVSPRODN, INDCPRODN, *AFPRPOLCY*, *ATRDREGIM*)... [22]

WATRINSTN = ***f23*** (CLCIMPACT, CLIMINVST, *LANDTENUR, CUSTINSTN*) .... [23]

WATRINFRA = ***f24*** (CLCIMPACT, CLIMINVST, *STAXPOLCY*) .... [24]

WATRAVAIL = ***f25*** (CLCIMPACT, CROPSHIFT, DCONVIMOD, *WATRINSTN*, *WATRINFRA, CLIMINSYS*) .... [25]

WATRSUPLY = ***f26*** (CLCIMPACT, WATRVAIL, *WATRINSTN*, *WATRINFRA* *CLIMINSYS*) .... [26]

AGPERFORM = ***f27*** (CLCIMPACT, WATRAVAIL, WATRSUPLY, *CLIMINSYS*)................................ [27]

CONFAMPPP = ***f28*** (AGPERFORM, *LANDTENUR, WATRINSTN, WATRINFRA, AGCRINSTN, RSPROVIDR, CORPSECTR*) .... [28]

CROPSHIFT = ***f29*** (AGPERFORM, CONFAMPPP, DCONVIMOD, *LANDTENUR, WATRINSTN, WATRINFRA, AGCRINSTN, RSPROVIDR, CORPSECTR*) .... [29]

DCONVIMOD = ***f30*** (AGPERFORM, CROPSHIFT, *LANDTENUR, WATRINSTN, WATRINFRA, AGCRINSTN, RSPROVIDR, CORPSECTR*) .... [30]

AGINSUPLY = ***f31*** (*ARESEXSYS, AGCRINSTN, RSPROVIDR*).. [31]

AMKTPRICE = ***f32*** (*AMKTREGIM*, *ATRDREGIM*) .... [32]

CULTICOST = ***f33*** (CULTIAREA, CROPATERN, AGINSUPLY, *STAXPOLCY*, *CREMINSUR*)... [33]

CROPINCOM = f_{34} (FOODPRODN, INDCPRODN, CULTICOST, *AVALCHAIN*, *MRKTPRICE*, *CREMINSUR*) .... [34]

RURALJOBS = f_{35} (LANDPRODY, LABRPRODY, RURALWAGE, FOODPRODN, INDCPRODN, LIVSPRODN, AGNFSECTR, *CREMINSUR*) .... [35]

RURALWAGE = f_{36} (LABRPRODY, RURALJOBS, FOODPRODN, INDCPRODN, LIVSPRODN, AGNFSECTR, *AGWAGELAW*) .... [36]

FARMINCOM = f_{37} (CROPINCOM, LIVSPRODN, AGNFSECTR, *SNETPOLCY*) .... [37]

LABRINCOM = f_{38} (RURALJOBS, RURALWAGE, LIVSPRODN, AGNFSECTR, *CREMINSUR, SNETPOLCY*) .... [38]

FOODAVAIL = f_{39} (FOODPRODN, LIVSPRODN, *AMKTREGIM*, *ATRDREGIM*).......... [39]

FOODPRICE = f_{40} (FOODPRODN, LIVSPRODN, *AMKTREGIM, AFPRPOLCY*).......... [40]

WATRSECUR = f_{41} (WATRSUPLY, *CUSTINSTN*) .... [41]

RUWELFARE = f_{42} (FARMINCOM, LABRINCOM, FOODAVAIL, FOODPRICE, WATRSECUR) ...... [42]

The following key features of the system of equations [1] to [42] and their methodological implications deserve to be highlighted.

(1) The 12 underlined variables in the equation system relate to institutions (e.g., WATINST, ENPOLCY, RESEXTN, INPUSUP, AMARKET, ATPOLCY, WAGELAW, etc.) and infrastructures (WATINFR and FOODSTO).

(2) The equations display both sequential linkages as well as simultaneous relations among them. Instances of simultaneous relations include equations [6] and [7], where AOUTPUT and APRICES appear simultaneously both as dependent and as independent variable.

(3) Of the 34 variables in the system, 16 are dependent (endogenous) and 18 are independent (exogenous) variables. The dependent variables capture and transmit the impact of climate change, the effect of four transformative adaptation options, and the role of institutional and infrastructural elements of MPG structure throughout the entire system, reflecting finally on the ultimate dependent variable: WELFARE.

(4) Independent variables include 12 institutional and infrastructural variables plus those capturing CCHANGE, SCITECH, and AMANAGE.

(5) In view of the sequential and simultaneous linkages within the equation system, the effect of any marginal change in any of the independent variable in the previous equations will be transmitted

in all equations in the system. This is an important structural feature, which will be utilized to track down the effects of transformative options and the performance implications of various institutional and infrastructural elements of MPG structure.

(6) The evaluation can be performed by converting the equation system into a single but long chain equation, where each of the equations in the system is appropriately embedded. By differentiating this single equation with respect to each of the 18 independent variables, the relative change in the performance enhancing roles of different institutional and infrastructural elements that together characterize MPG can be evaluated.

And, finally, it can be noted that the analytical framework specified in Figure 4 and the model defined by the equation system [1] to [42] are neither complete nor final. For instance, neither does Figure 4 exhaust all possible impact pathways nor does the equation system capture all chains of variables underlying even the impact pathways analytically delineated in Figure 4. Importantly, the set of transformative options to be considered for final evaluation has not been finalized. More work is needed to refine and finalize the both these elements of the proposed methodology. At this stage, therefore, Figure 4 and the equation systems [1] to [42] are rudimentary, tentative, incomplete. They only provide a feel for the kind of methodology that can be eventually developed and empirically applied under the proposed research.

7. Empirical Issues and Options

While the analytical and practical utility of the equation system specified in [1] to [42] are fairly clear, the main challenge lies in generating appropriate information needed for its empirical estimation. Considering the inherently *ex-ante* nature of impact transmission process, it is hard to get observed or quantitative information on many variables in the system. Even if we can have observed information on some variables, they relate to a past situation, making them less appropriate to capture current and future conditions. Still more difficult is to get objective data on variables representing the institutional and infrastructural elements of MPG structure, especially on their diverse roles and performance impacts both within and across impact pathways.

The deficiency or lack of observed data on most variables does not, however, mean a complete absence of information. In fact, highly relevant information is constantly being processed, coded, and stored as perceptions in the minds of individuals involved in development process either as planners, experts, evaluators, and beneficiaries or just as informed observers. Such real, but latent, information embodied in individuals can be tapped through carefully designed and conducted stakeholder surveys. Interestingly, this form of information has many desirable properties often missed in the so-called objective or observed data. For example, unlike the observed data characterizing a past and static situation, the perception-based data, when elicited carefully, can be a synthesis of the objective, subjective, and aspiration-related factors as well as the ex-ante and dynamic elements. The use of such perception-based data also has a strong theoretical legitimacy and considerable empirical precedence.[5]

Given the rationale and legitimacy of using perception-based data in the context of institutional analysis, they can be generated by delineating suitable empirical and spatial context and by selecting appropriate stakeholder sample. With efficient survey tools and appropriate stakeholder sample, it is possible to collect valuable information needed for the empirical evaluation of the model specified in equations [1] to [42]. Such information will usually be recorded as scores on a scale of 0-10 with zero denoting no effect and 10 denoting highest possible impact. In the case of quantifiable variables (e.g., output, income, employment, food supply, etc.), such scores can also be converted into quantitative equivalents by using the range of minimum and maximum values from published data.[6]

The detailed questionnaire for collecting such perceptional and qualitative information on all relevant variables included in the equations system [1] to [42] is included here as Annex-A. Annex-A also includes instructions for completing the questionnaire as well as definitions and explanations of key concepts and variables. The questionnaire needs to be field-tested to ascertain its efficacy and to be suitably adjusted and finalized based on experience and feedbacks. The adjusted and revised questionnaire will be the basis for collecting information for the empirical application and evaluation of the climate change-TAO-MPG-Welfare interactions and their climate resilience implications.

[5] The theoretical legitimacy comes from the subjective nature of institutions (Douglas, 1986; Ostrom, 1990), stakeholders as 'agents of institutional change' (North, 1990), and the human practice of 'adaptive instrumental evaluation' (Kahneman and Tversky, 1984; Bromley, 1985). The empirical precedence includes studies on institutional analysis (e.g., Gray and Kaufman, 1998; Kaufmann, et al., 2006) and impact assessment (e.g., Neubert, 2000; Coudouel, Dani, and Paternostro, 2006; Saleth and Dinar, 2008).

[6] Notably, when using qualitative variables within cross-sectional regression, the results in terms of the sign and magnitude of their estimated coefficients will not be qualitatively different regardless of whether the scores or quantitative equivalents are being used.

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