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# EVALUATION OF EXISTING CLIMATE-CHANGE ADAPTATION PLANS FOR MUNICIPALITIES IN MEXICO: PROPOSITION OF A "SUSTAINABLE MAC-WATER FRAMEWORK" THAT CONSIDERS VULNERABILITY TO IMPACTS ON WATER RESOURCES

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# EVALUATION OF EXISTING CLIMATE-CHANGE ADAPTATION PLANS FOR MUNICIPALITIES IN MEXICO: PROPOSITION OF A *"SUSTAINABLE MAC-WATER FRAMEWORK"* THAT CONSIDERS VULNERABILITY TO IMPACTS ON WATER RESOURCES

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**Professor Timothy J. Downs, D. Env. Chief Instructor**

# ABSTRACT

**EVALUATION OF EXISTING CLIMATE-CHANGE ADAPTATION PLANS FOR MUNICIPALITIES IN MEXICO: PROPOSITION OF A *"SUSTAINABLE MAC-WATER FRAMEWORK"* THAT CONSIDERS VULNERABILITY TO IMPACTS ON WATER RESOURCES**

Tsanta Noronavalona Rakotoarisoa

This paper presents a sustainable adaptive capacity framework for water management for municipalities, named Sustainable MAC-Water framework, after assessing the strengths and weaknesses of adaptive capacity in Mexico and its municipalities. It provides municipalities with an instrument to help them create sustainable adaptive capacity plans (Sustainable MAC plans) to prevent adverse impacts on water resources and related sectors. It is based on a study of policy instruments crafted by the Intergovernmental Panel on Climate Change (IPCC) and the Government of Mexico, and literature on adaptive capacity, assessment, and planning. The Sustainable MAC-Water framework recommends the establishment of a Reactive Barriers Removal Plan (RBRP), support measures in reaction to the negative impacts of adaptive measure, and an Integrative Social-Stakeholder Engagement Strategy (iSSE) along with adaptation plans. It also requires transparent leadership and the incorporation of health dimensions. There five components are additional requisites to build strong and resilient adaptive capacity and forms Sustainable Adaptive Indicators.

Keywords: adaptive capacity, sustainability, climate change, municipality, Mexico

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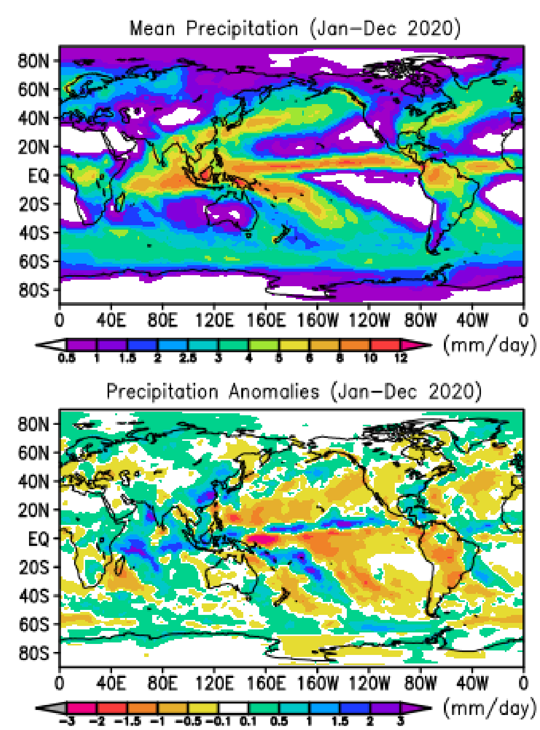
# INTRODUCTION

## 1. Observed and projected impacts of climate change

Without water, life on Earth cannot be maintained. Sadly, the capacity of the Earth to supply a growing human population with sufficient volume and better quality of water are threatened by the changes observed and projected in the Earth's climate conditions. In 1995, the Intergovernmental Panel on Climate Change (IPCC) alerted the world about the impacts of increasing greenhouse gases (GHG) concentration in the atmosphere compared to the pre-industrial period (IPCC, 1996: AR2, p.15). By 2100, the average surface temperature of the globe could reach 1-3.5°C above the 1850–1900 levels and create abnormal precipitation, resulting in catastrophic floods, droughts, fires, sea level rise, and deteriorated human and ecological health, at the same GHG levels (IPCC, 1996: AR2, p.3). But global warming has already reached +0.98°C in 2020, and precipitation anomalies have been clearly identified as shown in Figure 1 (NOAA, 2021).

*Figure 1: Global precipitation anomalies in 2020*



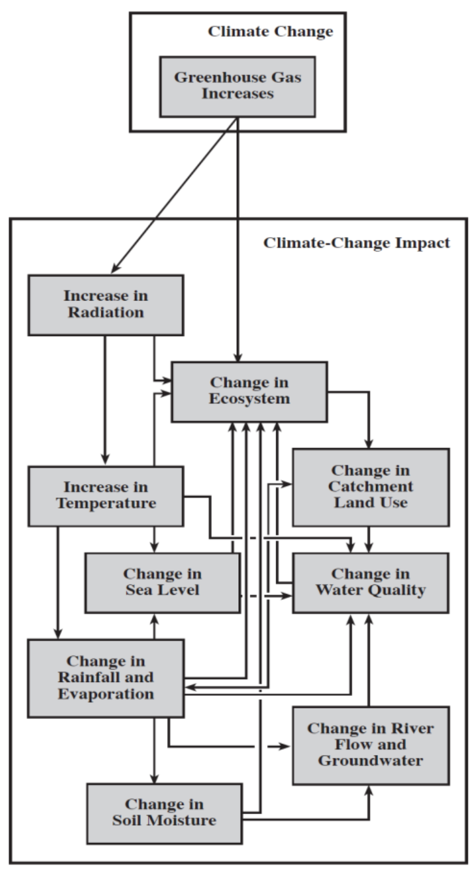

Source: NOAA, 2021

According to the IPCC, the hydrological cycle will be further disturbed due to climate change (IPCC, 1996: AR2). Water vapor increases, and run-off follows the precipitation anomaly. The rising temperature warms lakes, streams, wetlands, and oceans, threatening lives depending on these ecosystems as the level of oxygen is reduced, to melt the mountain glaciers (IPCC, 1996: AR2, p. 6). In addition to a lower water quality, the annual global water quantity per person is reduced, reaching below 1,000 $m^3$ (IPCC, 1996: AR2, p. 8). In some regions, climate change increases the duration, frequency, and intensity of floods, in others it accentuates droughts, reducing the volume and quality of water supply and deceasing biological productivity (IPCC, 1996: AR2). Figure 2 gives us an in-depth understanding of the impacts of climate change on the hydrological system and water resources.

## 2. Vulnerability of Mexico

The vulnerability of the hydrological cycle and water resources of Mexico to climate change were communicated to the United Nations Framework Convention on Climate Change (UNFCCC) in its First National Communication (SEMANART-INECC, 2001, p.50). The annual temperature in Mexico City will increase to 2.1°C if the $CO_2$ emissions double from the 1998-baseline of 389,087 kt (SEMANART-INECC, 2001, p.41, and World Bank, 1998). At this projected temperature, the quality and availability of water in the country will be highly affected, in addition to the impacts of the existing 178 pollutants responsible for the depletion of the ozone layer, air pollution in urban basins, water pollution, and hazardous waste and toxic substances in the country (SEMANART-INECC, 2001, p. 29). Concerning the precipitation changes, they were already felt when successive torrential rains in 1985, 1998, and 1999, and hurricanes in 1982, 1988, and 1995 hit the country (SEMANART-INECC, 2001, p. 56). The projected reduction is estimated to be 10 to 20% of the annual

*Figure 2: Impacts of climate change on water resources*

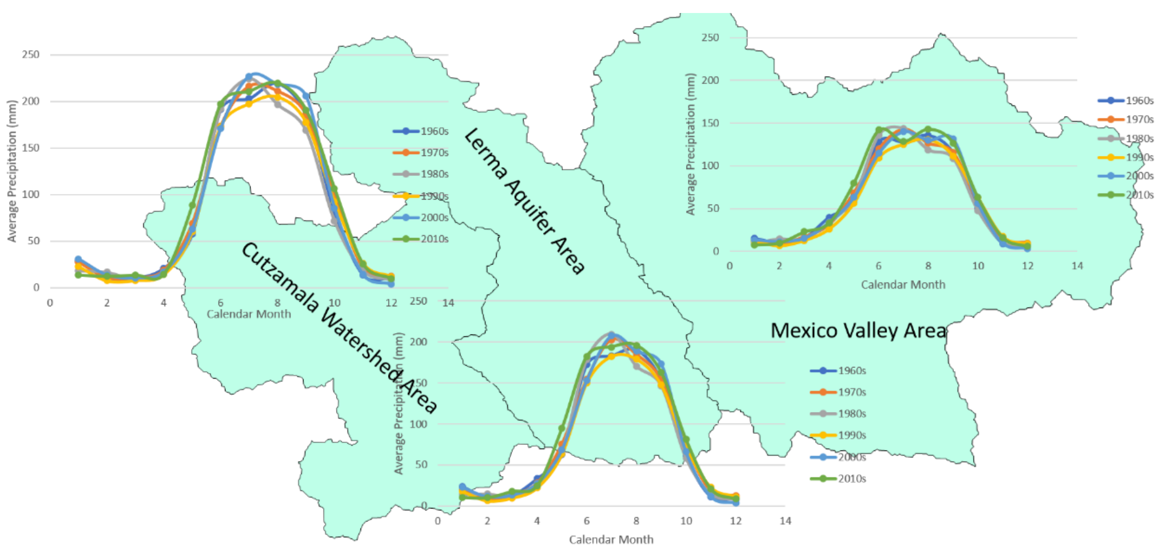



Source: Arnell, 1994, as cited in IPCC, 1996 precipitation of the country, (Government of Mexico INDC, 2015, p.6).

### 3. Vulnerability at the municipal level and the study region

The Valley of Mexico Metropolitan Area has been identified as a big contributor of 12% of the national greenhouse gas emissions (SEMANART-INECC, 2001, p. 48). It is also vulnerable to temperature and precipitation changes. Current precipitation changes are demonstrated by the preliminary findings of Ravi Hanumantha, a contributor to the larger team research this paper contributes to. The research team is composed of faculty and students at Clark University, Worcester, Massachusetts, USA, in collaboration with the National Autonomous University of Mexico (UNAM), Mexico City, Mexico. The team targets three major watersheds as a study region: the Mexico Valley area, the Lerma aquifer area, and the Cutzamala watershed area (Figure 3). Together, there are 193 municipalities in these three basins. Using seasonal trend analysis via GIS for the three different watersheds from 1960s to 2010s, Hanumantha shows that the average precipitation level has increased in the three watersheds, indicating that the water availability in these areas is more likely to decrease. Figure 3 also shows that the Mexico Valley Area has less

*Figure 3: Study region in 3 major basins, Mexico*



precipitation than its neighboring areas; therefore, water is less available in this area than in the Lerma and Cutzamala areas.

Furthermore, when delineating the Mexico Valley Area, Ravi's research showcases the watersheds and municipalities where the greatest population growth and the greatest urban land cover growth stress water demand. Figure 4 highlights the two most impacted watersheds in the Valley of Mexico.

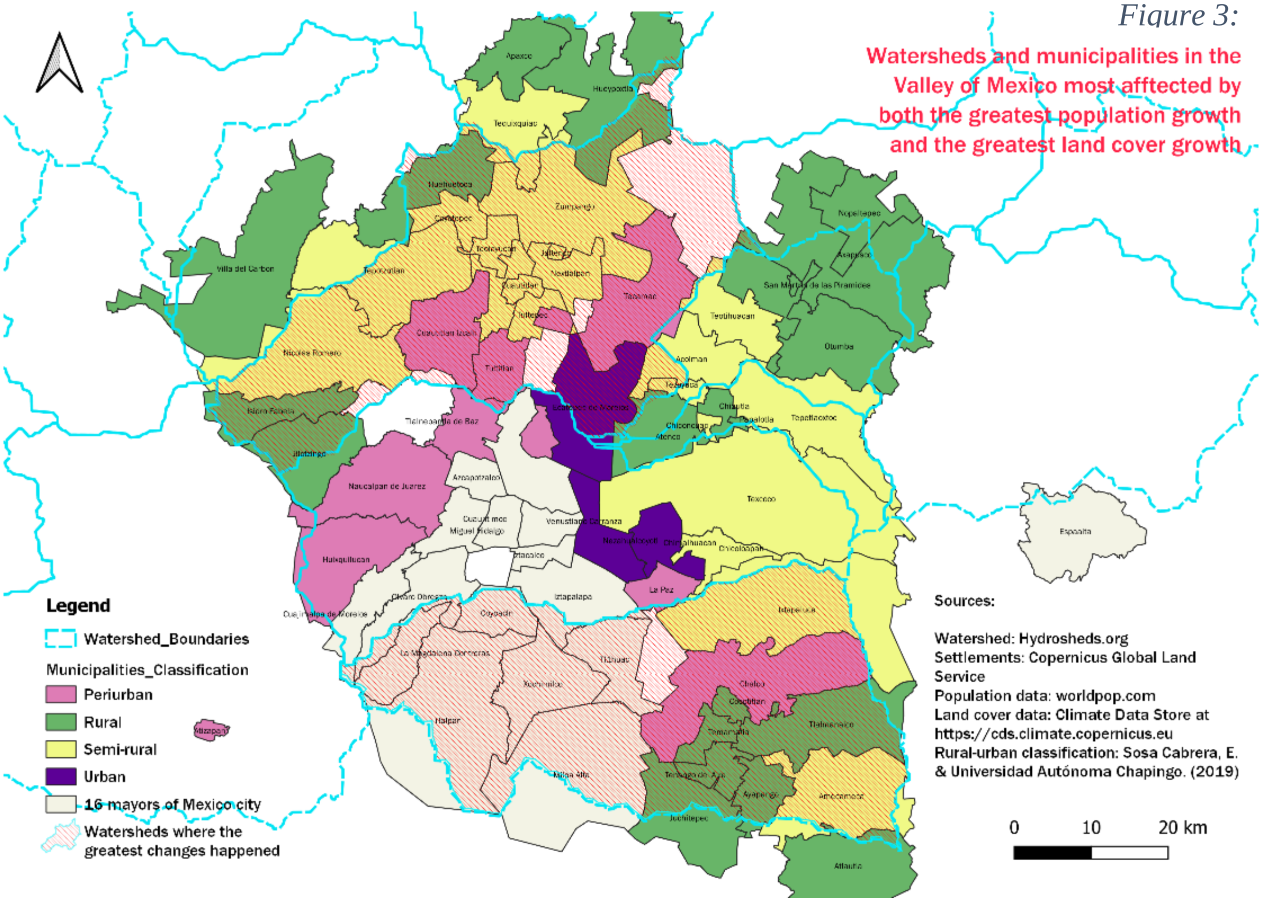
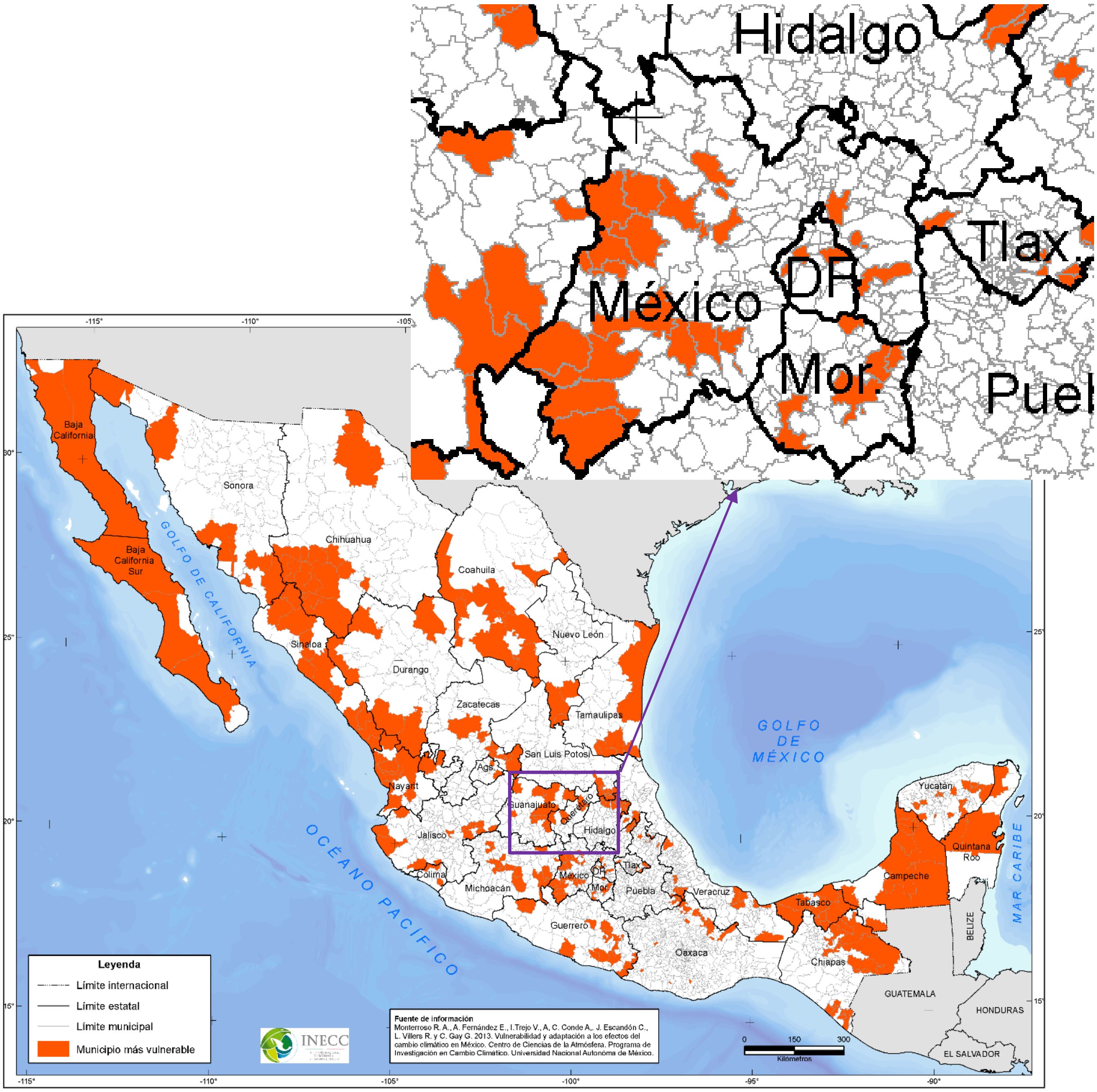



*Figure 3:* Watersheds and municipalities in the Valley of Mexico most afftected by both the greatest population growth and the greatest land cover growth

## 4. Research question and goal

In response to these impacts of climate change in the study region, the team interrogates how adaptive capacity can be built to ensure the resilience of region to climate change while avoiding maladaptation. This paper aims at addressing that question. More specifically, this paper reacts to the preliminary findings described above and aims at producing a framework that helps build sustainable adaptive capacity for municipalities where water demand is greatly stressed by climate change, population growth, and land use change, for municipalities where adaptation plan

*Figure 4: Municipalities most vulnerable to climate change by state in Mexico and in the study region of the large research team, at the upper-right corner.*




Source: INECC, 2014

seems missing, and for the most vulnerable municipalities identified in 2014 by the National Institute of Ecology and Climate Change (INECC) presented in figure 5.

The hope is to mitigate those vulnerabilities by building sustainable adaptive capacity which could be interpreted as the means to transform a vulnerable state into a resilient state. Resilience is the state of remaining functional when anything disturbs the system (St. George Freeman et al., 2020). Adaptive capacity, also known as adaptability, includes the preparedness to shield future disturbances and the aptitude to tailor the system in response to the impacts of stresses (Smith et al., 2001, as cited in  Engle, 2011, p. 1). Adaptation then could be either anticipatory or reactive (Smit et al., 2000, as cited in Engle, 2011, p. 1). The IPCC combines both conceptualizations of adaptation and defines it as the "adjustment in natural or human systems in response to actual or expected climatic stimuli or their impacts'' (Parry et al., 2007).

However, it is possible that adaptation is qualified as maladaptation when the adaptation aggravates the impacts of stresses instead of alleviating them (Rappaport, 1977, as cited in Engel, 2011). The framework created in this paper is designed to improve municipalities adaptive capacity to be more resilient against the impacts of global warming and precipitation anomalies.

There are legitimate reasons to pursue the purpose of this paper. Firstly, this paper hopes to support Mexico in reaching its national adaptation goals by 2030. Since the detection of its vulnerability in 1998, Mexico focused on crafting mitigation strategies to maintain the temperature below 2°C (Secretaría de Medio Ambiente y Recursos Naturales & Instituto Nacional de Ecología, 2001). Since then, the nation has started to develop mitigation plans and to produce books, newspapers, periodicals, workshops, lectures, courses for educational, private, and public institutions to raise its inhabitants' awareness about these climatic realities (p.50). Mexico's adaptation measures started to be popular since 2015 when the country submitted its "Intended Nationally Determined Contribution" (INDC) to the UNFCCC. Adaptation efforts are prioritized on building the resilience of the communities, the ecosystems, and the infrastructure

(SEMARNAT-INECC, 2016, p.11). The social goal is to reinforce the adaptive capacity of minimum a 50% of the most vulnerable municipalities (Government of Mexico INDC, 2015, p.3). Mexico has 9 years left to reach those first national adaptation goals; therefore, offering municipalities with a sustainable adaptive capacity framework with lessons learned and good practices from the past and elsewhere could support them in the implementation of the actions for 2020-2030 stated in the INDC (p.6) and at the end boost their adaptive capacity.

Secondly, after conducting internet research on 82 municipalities among the 193 municipalities of the study region, looking for adaptation efforts, we have estimated that about half of the municipalities in the Valley of Mexico do not have traceable adaptation plans against climate change to manage water resources resiliently. Providing vulnerable municipalities with a sustainable adaptive capacity framework could help them have a detailed guidance of what to assess and to consider when building resilience capacity to the stress of climate change on water resources. Once involved parties at the local territory have a clear plan, they would be able to anticipate the real impacts of climate change on their settlement and on the biological and human populations living there and to alleviate them.

This paper begins with presenting the methods used to come up with suggested strategies, then a brief overview of adaptation frameworks that guide international and national actions. After that, the strengths of the adaptation policy in Mexico and its municipalities are assessed, and opportunities of adaptive capacity growth are presented firstly in the results section. Secondly, gaps observed in the implementation of the adaptation strategies are analyzed. This paper, then, recommends further strategies to the Mexican municipalities to address the observed gaps. Finally, the Sustainable MAC framework is designed to further close the gaps and encourage the strengths of adaptive capacity in Mexico and its municipalities.

## METHODS

The sustainable adaptive capacity framework for municipalities (Sustainable MAC) in this paper is created by studying the adaptation policy documents at the international, federal, and city levels.

Firstly, the design involved the analysis of the scientific information regarding the impacts of climate change, and adaptation planning in the IPCC Assessment Report 2 (AR2, 1996). Many clues on how to build adaptive capacity from the Second Assessment Report (AR2) were used to inform the Sustainable MAC-Water framework. From the AR2, this paper extracts all information relative to adaptive capacity to base the vision of the *Sustainable Municipalities Adaptive Capacity framework* for water management. A major part of this information includes several baseline conditions upon which adaptive capacity should be built.

Secondly, internet search of the existing climate change policy at the federal, state, and municipal levels was conducted and studied to identify their strengths and weaknesses, but also to recommend areas and ways of improvements. I found out the following planning instruments established at the federal, state, and municipal level:

- the first and second communications of Mexico to the UNFCCC,
- the Intended Nationally Determined Contribution (INDC) communicated to the UNFCCC,
- the Special Climate Change Program of Mexico 2014-2018 or PECC 2014-2018,
- the Mexico’s mid-century strategy: this is the latest policy instrument that guides mitigation and adaptation efforts at all administrative level. It has 10-year, 20-year, and 40-year targets.

- The Municipal Climate Change Program (PMCC): it is a planning instrument that defines mitigation and adaptation measures for the municipalities in Mexico. Existing PMCCs of four municipalities were analyzed: Queretaro, Jalisco, Juanacatlan, and Puerto Vallarta.

I also explored the planning of water management at a local scale to analyze the strengths of adaptive capacity in Mexico. The study of St. George Freeman et al., (2020) on water management in Mexico City via the Resilience by Design (RbD) approach on the Greater Metropolitan Supply System of Mexico City (GMSS) which combines the Lerma, Cuztamala and Mexico City areas, was consulted.

Thirdly, a gap analysis in the adaptive capacity of municipalities was conducted by conducting a case study on Atenco, a rural municipality located near Mexico City. Atenco was chosen randomly. Other case studies from other countries were used to inform areas and ways of improvements for the Mexican municipalities. Further case studies on diverse municipalities in the study region are necessary when time allows because the gap analysis gives a power to plan for improvements.

Lastly, recommendations are provided and framed as *Sustainable MAC framework* to remove those gaps and prevent maladaptation. To further inform the Sustainable MAC framework, relevant elements related to climate adaptation in different sectors including water, agriculture, health, social equity, public policy, and technology from few other sources were looked at to detail the baseline conditions necessary for building adaptive capacity, to consider planning strategies against the direct and indirect impacts of climate change on the social-ecological system, and to guide the assessment of adaptive capacity at the municipal scale with reduced risk of maladaptation.

## Results and Discussion

### 1. Existing adaptation planning models

#### 1.1. What does the IPCC say about how adaptation planning should look like?

The Second Assessment Report of the IPCC have many clues on how to build adaptive capacity. This section extracts all information relative to adaptive capacity from the AR2 to guide the design of adaptation plans and actions.

The AR2 directs adaptation planners to assess baseline conditions which can be used as reference for adaptability. The baseline conditions in the water sector mentioned in the AR2 are as follows: climate conditions, geographical features, water sources and size, water demand, water supply system, population growth, responses of water resource managers towards the changes in the climate conditions, the population growth and the demand for water, existing technology, economic conditions, social conditions, and legislative conditions.

According to the IPCC, four criteria are necessary to build adaptive capacity towards the impacts of climate change (1996):

1- access to technological advancement thanks to internal research and development or by importing technological advances (p. 4),

2- appropriate set up of the educational, cultural, managerial, institutional, legal, and regulatory systems (p. 5),

3- sufficient and stable financial resources,

4- and the possibility to share and acquire information (p.4).

Last, the AR2 cites few examples of adaptation efforts for water resource management including water purification, regulation of water runoff, flood controlling, monitoring water availability in $m^3$ per person per year from different water sources, from the inside and outside of the territory, and for different sectors where water is used, monitoring water quality, integrated management system, and economic and environmental cost of management initiatives.

## 1.2.The Mexican adaptation policy

The policy guidance on adaptation actions described in the mid-century strategy is highlighted as follows (SEMARNAT-INECC, 2016, pp 49-54).

*Line action A1: Reducing vulnerability and building a resilient society*

Human-based adaptation is the approach used for this line action A1 in response to the impacts of climate change on the water system and on the wellbeing and health of the society. The objective is to reduce the vulnerability of the society to water scarcity, flood, droughts, diseases, and to increase the ability of the inhabitants to be resilient to these impacts.

*Line action A2: Infrastructure and productive systems*

Most sectors in an economy need water. Fishing, aquaculture, agriculture, industries, power generation, health care services, and homes all depend on water to operate; therefore, all these sectors are touched by the impacts of rising temperature and precipitation anomalies on the availability and quality of water supply. Thus, each water-reliant sector needs adaptive capacity to reduce their vulnerability to the impacts of climate change.

*Line action A3: Ecosystems-based adaptation*

Climate change also threatens ecosystems and their biodiversity. The mid-century strategy of Mexico guides adaptation actions that promote the sustainable exploitation and restoration of local ecosystems. Restoration of watersheds is particularly mentioned in the INDC to enable the restoration of their ecosystems and biodiversity.

More detailed measures are defined under each of these three lines of action. Prioritization and decision-making on adaptation measures should follow not only the performance targets set by the stakeholders but also the guidance of the national climate policy. The Mid-Century Strategy directs all adaptation proposals to be feasible, budgeted, synergistic, provider of co-benefits, aligned with national, state, and local policy, evaluable with indicators and units of measurement, credible, a no regret solution that does not create negative impacts, reversible, and with informed barriers" (SEMARNAT, & INECC., 2016, p.44).

## 2. Strengths and areas of improvements in the existing planification and implementation

### 2.1. Strong will to enforce strategies through public policies

The mid-century strategy of Mexico guides all adaptation actions decided in Mexico across its administrative levels (SEMARNAT-INECC, 2016, pp 49-54). The line action A1.6 defined in that policy instrument specifies the "*implementation and strengthening of public policies to guarantee water quality and quantity availability in priority zones, and to strengthen eco-hydrological services provided by ecosystems"* (SEMARNAT-INECC, 2016, p.50). The line action A1.8 also demonstrates the goodwill of the public policy arena to enforce adaptation strategies by stipulating the *"implementation and strengthening of public policies focusing on reducing health risks associated with climate change impacts*" (ibid).

A good example of application of these stipulations is the Law on Mitigation and Adaptation for the State of Hidalgo, Decreto No. 526, published in the Official Gazette on Monday, August 26, 2013, and reformed to meet the guidance of the government's Mid-Century Strategy. The reform was published in the Official Newspaper, on April 1, 2019. This law is interesting because it "*provides guidelines for cross-cutting, interdisciplinary and multidimensional incorporating actions that take into account state and municipal needs, as well as the role of individuals in adaptation policies and strategies"* (Decreto Num. 526, Septimo). Another example, the creation of an *Atlas of Environmental Risks* is planned as an adaptation measure for the State and municipalities of Hidalgo and has been enforced into law through the Decreto No, 526, Article 4.3 to assure it is carried out. This article also enforces the conservation and restoration of the ecosystems, and the reinforcement of the adaptive capacity of human-ecological systems.

### 2.2. Consciousness about stakeholder participation, public participation, networking, and collaboration

The international, national, and local climate policies of the Government of Mexico reflect that it understands the necessity of incorporating stakeholders' perceptions and social participation in the planification and prioritization of adaptation policy, programs, and projects.

The INDC of the Government of Mexico specifies its commitment to contribute to *"inclusive social participation in climate change planning"* and *"to create a platform where all levels of government and all stakeholders network via an adaptation platform to share knowledge and practices"* (p. 7-8).

At the national level, the PECC and the Mid-Century Strategy direct all actors "*to implement transparent and inclusive public participation mechanisms in the design and implementation of climate change adaptation strategies. This may include communal, district, municipal, and state councils focused on reducing social vulnerability"* (SEMARNAT-INECC, 2016, p.50). The means to ensure public participation are outlined in the line action A2.3., by "*the creation of inter-municipal boards for defining and applying adaptation criteria in local production projects*" and through "c*ollaboration between municipal governments and local residents*".

A Portal of Municipal Climate Change Programs in Mexico is currently in operation. Through that platform, municipality leaders can write news about their experiences concerning the elaboration and implementation of their PMCCs, share success stories and best practices about their use of the Guide for the Elaboration of PMCC, and discuss with each other. The Municipal Governments of Jalisco and Puerto Vallarta are piloting the elaboration PMCC in the portal. The portal has a video introducing how to interact and collaborate through it.

An excellent existing project to foster networking and collaboration between municipalities in Mexico is the *Multi-City Challenge Mexico 2020*. SamDeJohn & Alsina (2020) reported on September 10, 2020 that the cities of Hermosillo, Reynosa, San Nicolás, San Pedro, and Torreón were selected by GovLab, an action research center located in New York University Tandon School of Engineering, United States, to participate to this challenge. In 3 months, these municipalities are required to identify stressful public issues and solutions using a participatory approach at each stage of their actions. In addition, selected municipalities are assisted by public innovation experts, and trained at each step of the challenge.

## 2.3.Adoption of integrated water management

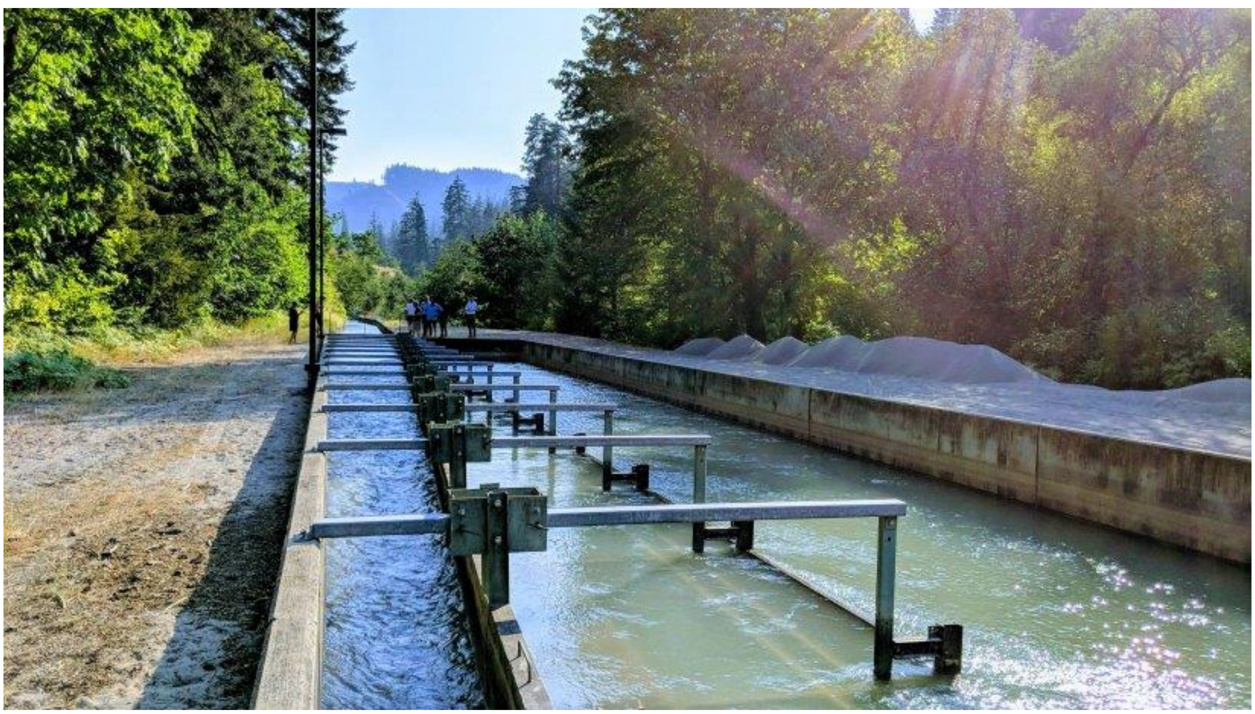
### 2.3.1. Insertion of integrated water management in the nation's climate policy

All policy instruments in Mexico are already looking adaptation and water management in an integrative way. The INDC directs actions towards integral watershed management and integral water management for agricultural, ecological, urban, industrial, and domestic usage. The Mid-Century Strategy strengthens these commitments, especially for water supply in agriculture by "*building quality infrastructure, employing state of the art techniques, and strengthening operations*", as stated in the line action A2.7 (SEMARNAT INECC, 2016, p.52).

### 2.3.2. Areas of improvement in Mexico and Atenco: Integrate water management with agriculture and hydropower generation

The agricultural sector needs adaptation measures in priority because of its high volume of water consumption. The *Gaceta UNAM* reports that the agricultural sector consumes about 70% of water in Mexico, of which 57% turns to wastewater from the agricultural sector because of the insalubrious and leaky irrigation infrastructures, while the total fresh water available in the country is as little as 0.1% and the domestic water use by around 130 million population is only 10%. It adds that 60% of stored water for agriculture evaporates or gets infiltrated (Maguey, 2018). These data suggest the need for construction of new irrigation infrastructures, or repair of the leaky ones to maximize the water services for agriculture.

*Figure 5: Farmers Irrigation District to water 5,800 acres of residential and agricultural land in Oregon*



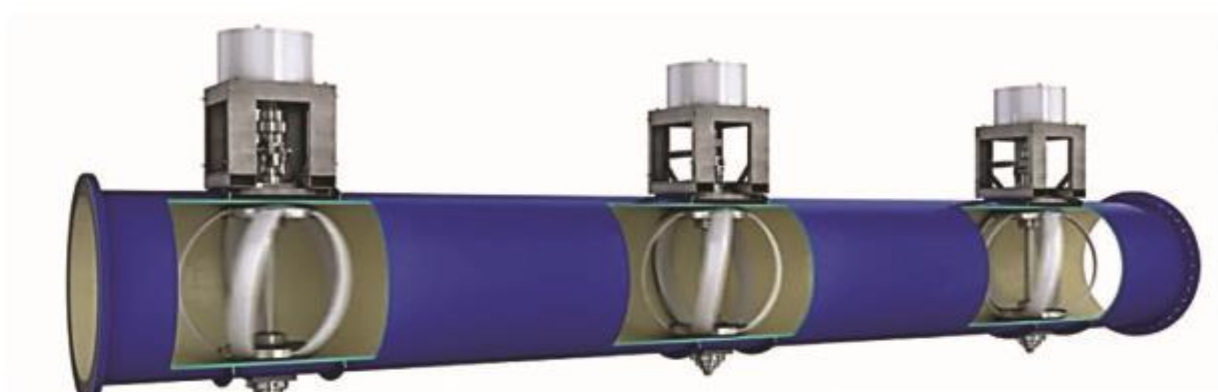
Source: Jed Jorgensen, Farmers Conservation Alliance, as cited in Office of Energy Efficiency and Renewable Energy, 2019

The case of Atenco falls in the scope of the line action A2.7 as it does not have sewage systems yet, according to the 2015 records of Data MEXICO, to treat all these 57% agricultural wastewater and other sectoral wastewater. An adaptation measure that responds to the infrastructure needs of Atenco is the repair of the leaky old infrastructure.

Or, instead of just repairing the old systems, it could be more sustainable to undertake a “modernization in irrigation” which can solve Atenco’s problems of leaks and evaporation loss by installing a “pressurized piping” while being used for agriculture (Office of Energy Efficiency and Renewable Energy, 2019). This type of promising infrastructure is in place in the Hood River, Oregon, USA (Figure 6). Modern irrigation systems can also be used to “install a conduit hydropower”, to produce food, and to restore biodiversity (ibid).

The “conduit hydropower” is a system of small hydropower formed with any water carriage infrastructure to irrigate water into agricultural fields, municipalities, or industries. Such system

*Figure 6: Spherical in-pipe cross-flow turbine (Lucid Energy)*



Source: Rycroft et al., 2016

can be pipelines or tunnels, and hydropower turbines installed inside the water carriage infrastructure to collect renewable energy from them, anytime and continuously. A visual of a conduit hydropower is shown in Figure 7. This technology is widely constructed across municipalities in South Africa where water is one of the scarcest resources of the country (Rycroft et al., 2016).

### 2.3.3. Integrated human-hydrological model in Mexico City

To confront an uncertain future, St. George Freeman et al. confirm the necessity of using an integrated approach based on performance targets defined with the stakeholders to mitigate the impacts of climate change at the local level (2020). They realized that for long, the planning of water resources in Mexico City has directed efforts on the physical hydrological system within the borders of the city alone. St. George Freeman et al. (2020) reported that multiple studies have revealed this management style as unable to ensure the sustainability of the system towards the concerns about increasing water demand, over-pumping of aquifers, flooding, urban drainage, and future climate risks. The failure of the conventional water management in Mexico City has led to the understanding that the resilience of freshwater systems and urban systems needs to be managed with the understanding that both systems are interdependent (St. George Freeman et al., 2020). Urban settlements need freshwater supply from sources outside their borders as their own systems are usually not able to meet the needs of a dense and growing urban population. Freshwater systems are also stressed by the development of urbanization.

Therefore, for the sustainable planning of the water system in Mexico City, the integrated approach consists in planning resilience based on a quantitative engineering and human participatory performance-based approach for all interdependent systems, not just one system. St. George Freeman et al. studied the human-hydrological system in Cutzamala and Alto Lerma watersheds where water consumed in Mexico City comes from. These three systems together form the Greater Metropolitan Supply System of Mexico City (GMSS) which could be managed according to the priority goals defined by the stakeholders in the affected region.

After pilot testing the RbD approach, St. George Freeman et al. (2020) further realized the efficiency of incorporating multiple performance targets in the framework when multiple user groups are considered in the assessment. The process has also revealed that equity in the access to water has a huge place in the preferences of the stakeholders; thus, it must be incorporated while designing resilience. Lastly, they learned that the resilience metrics applied on the interdependent systems need to be complemented with the inclusion of *investment risks and return analysis* to better evaluate how the tradeoffs associated with each engineering option could be compensated across the whole water system.

## 2.4. Promotion of techniques and technologies to manage climate risks

This is the line action A2.9 in the Mid-Century Strategy. Risk management begins with monitoring. The INDC and the Mid-Century Strategy require periodical monitoring and updating of the total water quantity and quality, specifically in areas containing more than 500,000 people (INDC, 2015, p.8 and SEMARNAT-INECC, 2016, p.52). In the water sector, the INDC also directs technological measures towards "*urban and industrial wastewater treatment, securitization of damns, strategic hydraulic infrastructure, and technology transfer in the water sector (savings, recycling, capture, irrigation, protection of river infrastructure)"* to mitigate climate risks on water supply (INDC, 2015).

To manage climate risks, risk assessment tools were created. Mexico City, for instance, is currently monitoring the hydrometeorological forecasting through an *Atlas of Hydrometeorological and Climate Risks*, and is installing early warning systems and emergency response programs (Sosa-Rodriguez, 2014, p. 982). The limits of monitoring identified by Sosa-Rodriguez is the lack of indicators for evaluation purposes (p. 984). Another study of the challenges of the water quantity and quality in Mexico City and its Metropolitan Area (MCMA) also reveals that the monitoring program of the water quality necessitates some improvements (Mazari-Hiriart et al., 2019).

Municipalities, businesses, and individuals can also use online tools such as *Iluminr* which monitors climate threats at a specific location, provides live data, and alerts users earlier enough before a catastrophe happen (“Iluminr Active Threat Monitoring for Risk Professionals,” n.d.).

In my view, the systemic monitoring needs capacity building of all institutions and employers involved in the scene of estimating water data because these information have the potential to overcome the resistance of the society to the municipalities’ efforts.

**2.5. Fight against social injustice**

Mexico is concerned about inequality. The line action A1.11 of the Mid-Century Strategy stipulates the “*design of social vulnerability reduction strategies which include a gender approach*” (SEMARNAT-INECC, 2016, p.50).

In addition, the national strategy requires the prioritization of the most vulnerable municipalities highlighted in orange, in Figure 5, when undertaking adaptation actions because its goal is to reduce the number of these municipalities by half by 2030.

## 3. Gap analysis and ways of improvements

### 3.1. Limited collaboration within and between Mexican municipalities

#### 3.1.1. Missing collaboration between municipal governments and residents

##### 3.1.1.1. The case of Atenco

Collaboration with residents implies that collaborative planning and local water-related projects must be decided upfront with residents to be efficient and safe. Otherwise, collaboration between municipalities would fail and cause conflicts between themselves and the residents if it were not participatory.

That was the case in San Salvador Atenco, a rural municipality located near Mexico City, when residents protested against the illegal pipe from the water well in front of the Parc of Los

Ahuehuetes, was being used to provide and sell water to other municipalities located on its eastern side (Fernández, E., 2020, August 27). Perhaps the recipient municipalities were Ecatepec de Morelos and Tecamac, two urban municipalities within the watersheds highlighted with red stripes as shown in Figure 4. Two-hundred residents were unhappy that the commercialization had taken place for 6 months already and the National Water Commission (Conagua) refused to disclose the project (Fernández, E., 2020, August 27).

This example is revealing for the Government leaders that the public wants to be part of the resources management and are concerned about the insufficient water being transferred in other places. Residents are direct users of water for their drinking needs and household care. Therefore, leaders in Atenco should adopt a public participatory approach when planning collaboration with other municipalities and local projects.

**3.1.1.2. Model of successful municipalities-residents collaboration in Norway**

Levanger and Verdal are two municipalities in Norway which collaborate to undertake joint services. They did not have efficient health equity planning before implementing the *Health and Equity in All Policies* (HEiAP) which has been enforced by the Norwegian legislation in the Public Health Act, the Local Government Act, and the Planning and Building Act (Von Heimburg & Hakkebo, 2017). The HEiAP is a system that consists of integrating health policy in all policies and for all inhabitants and has become a best practice since its successful implementation in Norway.

Levanger and Verdal organized joint events to hear from their inhabitants' perspectives, knowledge, culture, and ideas to include them in the HEiAP planning (Von Heimburg & Hakkebo, 2017). Parents' organization, for instance, were consulted to understand and frame the real health and inequality issues in the "childhood, education, culture, business, industry, and city area" and to co-plan with them health programs for each of these domains (ibid, p. 69). Thanks to this participatory governance system across the two municipalities' territory, their residents got the feeling of security and power and it led to the successful implementation of the HEiAP policy.

This bottom-up practice led by the municipalities' leaders in Norway is a good example of measure for the municipalities' leaders in Mexico in the face of the water crisis faced by the most vulnerable municipalities of Mexico.

### 3.1.2. Challenging inter-municipal collaboration

#### 3.1.2.1. The case of Mexico City

The study of Sosa-Rodriguez (2014) remarks that adaptation was limited in Mexico City because adapting to climatic changes were perceived as the affair of the federal government mainly, namely the Ministry of the Environment. As a result, the cooperation and collaboration between municipalities were lacking (Sosa-Rodriguez, 2014, p. 284). In addition, competition over the resources between sectors and over the power between agencies made it difficult for agencies and sectors to be coordinated (ibid). These limitations could be true for other municipalities surrounding Mexico City, especially for semi-rural and rural areas. Also, these limitations could have been one of the reasons the Government of Mexico put an emphasis on ensuring public participation in the new adaptation strategy defined in the Mid-Century Strategy for 2030, by creating inter-municipal boards through which municipalities can collaborate.

#### 3.1.2.2. A way of improvement: joint forces between two municipalities as in Norway

A successful collaboration in Norway provides an example of collaboration that could be a solution pattern to overcome the challenges of collaboration in Mexico. Joint forces between two or more municipalities could be more powerful and could gain more support from the national policy than acting by oneself as one municipality. As written by Von Heimburg & Hakkebo (2017), Levanger and Verdal, two adjacent municipalities, have provided common services together and integrated health interventions to all sectors. The national legislation was in favor of enforcing local Acts to increase the efficiency of those joint municipalities. When the municipalities gain strong governance capacity, they could be able to consult their population and identify with them indicators of progress that can be monitored periodically. Indeed, they were successful in gathering the necessary data because of close teamwork with their residents.

However, with the unhappiness of Atenco's residents and their fear of not having enough water left, as seen in section 3.1.1.1, would this Norwegian type of collaboration between municipalities work with municipal governments in Mexico? I do not think local population are yet ready for such collaboration. Thus, Mexico still needs to reinforce collaboration within and between municipalities because both ways of collaboration are interdependent.

#### 3.1.3. Recommendation: expand networking for collaboration

To increase collaboration "between and within municipalities", networking for collaboration should be expanded.

A portal to promote exchanges between municipalities is available on the energypedia.info website[1] where one can add an account to participate in the discussions or edit the PMCC blog. The portal of PMCC reveals a strong awareness raising for all actors involved in the planning process. The beneficiaries of the information are mostly the policy, programs, and projects leaders than the grassroots.

In addition, the portal should not be limited to the PMCC elaboration. Ongoing or in design water-related programs and projects should be posted there or in another official portal and should

[1] Blog PMCC - La transversalización del Programa Municipal de Cambio Climático como base fundamental para su implementación - energypedia.info

have a section to post public comments about them. Such extended networking platform could be a solution to build collaboration within municipalities.

Also, building specific networking within the same watershed, for instance, can enable municipalities which are highly vulnerable to climate change but do not have clear adaptation planning to easily get information and resources from others which have some experiences in adaptive capacity.

### 3.2. Health impacts not addressed in the planification

Although the quality and quantity of available drinking water and sanitation water are directly impacting human health, adaptation efforts on water management in Mexico do not integrate the health dimension.

The work of Riojas-Rodríguez et al. reports that below five-year-child mortality rate reaches 15.5%, and this rate is 12.7% for babies under 1 year old in Mexico (2018, p.282). These mortality rates were accentuated by the impacts of global warming and precipitation anomalies on the availability of clean water and sanitation. Children are dying from intestinal infections, acute respiratory tract infections (ARIs), a malnutrition rate of 10% in urban areas and 19% in rural areas, dengue, chikungunya, asthma, pneumonia, any other diseases, and a lack of hygiene (ibid, p.282). Riojas-Rodríguez et al. also inform the reader that heat rise has caused 393 deaths in Mexico during the 2002-2010 period; that number will double in 20 years affirms the World Meteorological Organization (WMO). Despite these significant public health issues, the inclusion of the health dimension in adaptation efforts is still weak in Mexico (Riojas-Rodríguez et al., 2018). By adding health indicators in designing and assessing adaptation capacity, this Sustainable MAC-Water framework strengthens the adaptive capacity of the whole system.

### 3.3. Gender inequity reduction was not included

Though the Mid-Century Strategy directs the Mexican adaptation actors to include a gender approach in social vulnerability reduction (line action A1.11), the consultation of the Mexican municipal climate mitigation and adaptation plans of Puerto Vallarta, Jalisco, Juanacatlan, and Queretaro, reveals that the gender approach was not mentioned in any of them.

Further efforts on identifying which gender type is most vulnerable to climate change in a municipal territory, and what are the impacts of climate change on them, are critical to adaptation because without a gender vulnerability approach, inequality is more likely to increase when decision makers and planners design adaption policies, programs, and projects. In that case, adaptation is maladaptive, accentuating the suffering of the most vulnerable groups due to climate change.

Also, these efforts are necessary to respect human rights because "*All human beings are born free and equal in dignity and rights*" and "*everyone is entitled to all the rights and freedoms …, without distinction of any kind, such as race, color, sex, language, religion, … birth or other status*." ('Universal Declaration of Human Rights', 1948). Men and women both have the right to access water equally.

Finally, once gender-related vulnerability to climate change is detected, adaptation measures can be implemented where the vulnerability occurs.

## 4. Design a Sustainable MAC-Framework to close the gaps and prevent maladaptation

The Sustainable MAC-Water framework intends to solve the gaps observed in the planification and implementation of the international, national, and municipal policy instruments presented in section 3.2.

This section presents the components of the Sustainable MAC-Water framework, suggested to build the adaptive capacity of municipalities in Mexico, especially where vulnerability is very high and adaptation plan is missing.

The Sustainable MAC-Water framework proposes detailed assessment and dissemination of the baseline conditions, the elaboration of Reactive Barriers Removal Plan (RBRP), support measures, and Integrate Social-Stakeholder Engagement strategy. It builds Sustainable Adaptive Capacity on these plans, on the level of leadership transparency, and on the impacts of climate change on health.

### 4.1. Detailed assessment and dissemination of the baseline conditions for an integral water system to construct assessment metrics

The business-as-usual conditions or the baseline conditions are used as metrics upon which adaptive capacity is designed, implemented, and monitored. It is important to start with the construction of metrics because the IPCC AR2 clarifies that pre-existing conditions are influencing the impacts of climate change on a region (1996). For long, baseline conditions are focused on the territory of concern alone. But to manage water resources resiliently, the baseline conditions to catalogue should be conducted on all other municipalities impacted by its water sourcing.

A catalogue of the baseline conditions of an integral water system is critical to the identification of the impacts of climate change on the concerned territories and gives more opportunities to guarantee the inclusion of all stakeholders, community groups, and sectors involved in water management and consumption. In addition, it will inform different ways of collaboration between municipalities and within their population. Also, since tools to visualize the impacts of climate change at the municipality scale are not available yet, according to the blog in the portal of Municipal Climate Change Program in Mexico, the Sustainable MAC framework requires the baseline conditions to be disseminated to the public in form of infographics, videos, and educational tools, and through an online platform integrating all municipalities.

The baseline metrics can be used as indicators for the prioritization of adaptation options, for the planning of adaptability, and for the evaluation of adaptive capacity. The metrics respond to the following questions:

- From which water sources does the municipality get its water supply? And what are the topographic, geographic, and demographic features of these sources? Mapping is an effective tool to visualize the geographic location of the water system with the municipal boundaries, watershed boundaries, and topographic elements. The elements that need to be mapped include:
  - Natural sources: lakes, rivers, groundwater.
  - Existing infrastructure and technology: wells, drainage, water waste treatment, others.
  - Topographic elements may include elevation and land cover.
  - Demography is about population count, density, and growth.
- How much water is available, supplied or extracted, and recharged by each source? How much water is demanded in total within the municipalities? Inventory of the following metrics would respond to these questions:
  - Volume of surface water storage capacity
  - Volume of groundwater storage capacity
  - Volume of water supply
  - Volume of aquifer extraction
  - Volume of aquifer recharge
  - Volume of water demand

Some of the above metrics can be sourced from the National Institute of Ecology and Climate Change website (INEGI, n.d.). Those which are not available on the website should be measured.

- In which sectors is water used within the municipality boundaries, and how much volume per sector is used? Which sector of the municipal economy is most dominant in water usage?
- What is the quality of the water?
- What are the climate features of the municipality and where its water is sourced? What are the climate changes observed and projected at the municipal and hydrologic scales?

According to the National Geographic Society, (2017), relevant climatic and social features include:

- Weather patterns of temperature and precipitation
- Seasonal variation
- Windiness
- Climate system such as tropical wet, tropical monsoon, tropical wet and dry, arid, semiarid, Mediterranean, humid subtropical, marine west coast, warm summer, cool summer, subarctic, and polar.
- Microclimates: for example, "urban heat island effect" occurs in a city when the mean temperature there exceeds the mean temperature in other neighboring and larger areas. The "lake effect" is a climate qualification given to cities that have excessing snow and clouds than other cities nearby.

- What are the social conditions at the municipality?

Social conditions include the culture, customs, traditions, level of education, gender trends, equity, human rights, livelihoods and income, health, and sanitation.

- What are the impacts of climate change on communities' livelihood, health, sanitation, and well-being?
- What are the ecological impacts of climate change at the municipal level and the water source systems?

Climate change brings changes to the water quantity and quality and to the land-use patterns. Consequently, the biological system relying on water and land are also impacted by climate change. A study of the ecological consequences of global climate change for freshwater ecosystems in South Africa shows for instance that the combination of different changes in the quantity and quality of water plus the changes in the physical habitat alter aquatic biodiversity, the phenology and life-history patterns, the distribution and range of species, increase the extinction of vulnerable species, increase invasive and pest species, and accentuate waterborne and vector-borne diseases (Dallas & Rivers-Moore, 2014, p. 50). These examples for the freshwater in South Africa show the necessity to assess the real impacts of climate change on the biodiversity of the studied municipality and the impacts on its water systems. Further questions are:

- What are the legislative conditions in place?
- What is the level of vulnerability of the water supply system within the municipality boundary and at the external water source systems?

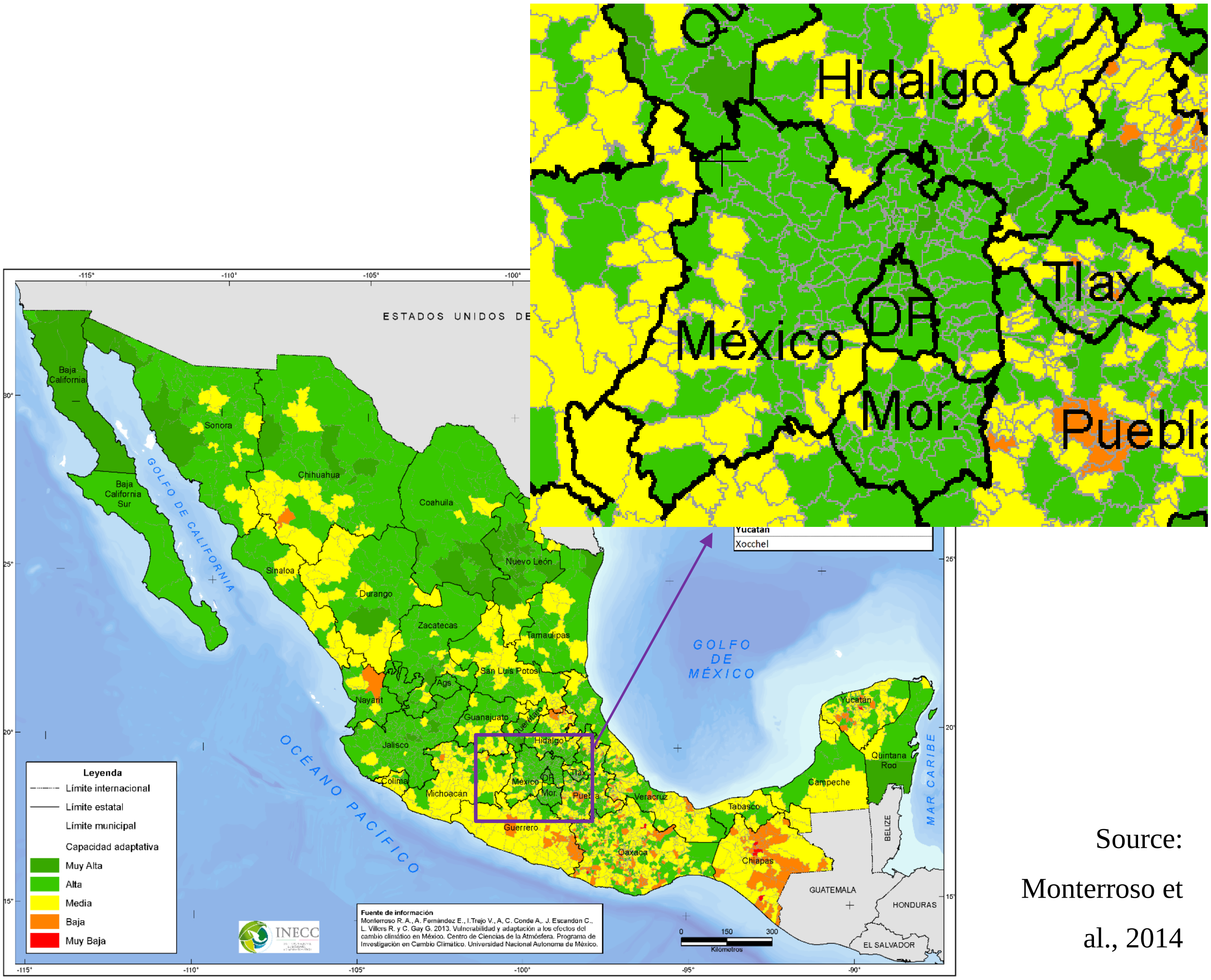
Vulnerability at the municipality scale within our study region is shown in Figure 5. This map can be used as a base level.

- What is the level of adaptive capacity of the municipalities within the study region?

The degree of adaptive capacity at the municipality level in Mexico has been assessed and is mapped in the Government of Mexico website (INEGI, 2016), as shown in Figure 8. Nevertheless, the gaps identified above indicate a need for improving adaptive capacity indicators at the

*Figure 7: Degree of adaptive capacity per municipality*

municipal scale. Therefore, I suggest in the section 4.7 more indicators to assess, monitor, and evaluate adaptive capacity at the municipality scale.




Source: Monterroso et al., 2014

## 4.2. Elaborate a Reactive Barrier Removal Plan (RBRP)

Though this Sustainable MAC framework is created for water resource management, the main strategy of this MAC-framework is to set adaptation measures that improve the water management system at the municipality level but also offsets the possible negative impacts of the measures on other sectors by selecting other adaptation support measures in the affected sector.

The goal is to provide municipalities with sustainable adaptive capacity plans (Sustainable MAC plan) that do not create or exacerbate negative impacts.

When analyzing diverse adaptation planning in the literature, barriers are known to exist and decelerate adaptative capacity. Engle clarifies that adaptation confronts “spatial and temporal scales”, and “cultural context and social goals” (Engle, 2011, p. 648). But with the hypothesis that barrier mitigation is less emphasized in the adaptation literature, the Sustainable MAC-Water framework suggests addressing all existing and potential barriers as part of adaptation strategies. When barriers are removed, adaptive capacity can be more sustainable and resilient.

### 4.2.1. Identification of the barriers’ resistance and the time necessary to remove them

To identify the barriers, identify what aspect of the culture, customs, traditions, social network, level of education, and social capital could be a barrier to or an opportunity for adaptation (IPCC, 1996).

For the Sustainable MAC Framework, the identification consists not only of assessing barriers and opportunity but also measuring their resistance, and the time needed to remove them. The time frame necessary to conduct these measurements need to be estimated as well and taken into consideration in the adaptation plan.

### 4.2.2. Example of barriers and components of a RBRP

Barriers could be educational, managerial, technological, economic, institutional, legal, and in the regulatory system. These criteria are supported by the IPCC AR 2 as vital for building adaptive capacity (1996, p. 5).

Some examples of barriers to adaptive capacity detected across this paper include the rebellion of the community against a project, negative perceptions, lack of understanding of a situation, non-inclusion of a gender approach in the planification, and distrust in the local government.

### 4.2.3. Case of social unrest in Atenco

As a concrete example in Mexico, the protest of local residents in Atenco against the illegal pumping of their wells to provide water in other municipalities is not an approval of inter-municipalities collaboration (Fernández, E., 2020, August 27). This barrier could have been removed if the mayor explained transparently what the pipes were for, if they were really for the neighborhood municipalities, and why they transfer some water out. In that case, the RBRP should elaborate steps and strategies to ensure transparency within an appropriate timeframe.

### 4.2.4. Case of gender exclusion in Bangladesh

A study of gender vulnerability on two divisions of Bangladesh by Rahman S., in 2013, shows that the mortality rate of female inhabitants due to natural disasters is higher than the rate for men.

In Bangladesh, even before disasters, women have less access to higher education and their position in the society are restricted to some type of employment, leaving them working in the agricultural sector and caring for domestic chores such as fetching water. They are also the first responsible for the protection of their flocks, household resources such as water and fuel, and their children, during disasters. Moreover, they are culturally subordinated, thus have less adaptive capacity in face of disasters. They are also suffering of sexual violence especially when natural disasters accentuate their poverty. Due to all these pre-disaster conditions, when natural disasters hit their activities and resources, women are the most affected, even after the disasters.

To cope with the utmost vulnerability of women due to climate change, Rahman S. suggests essential strategies to build women adaptive capacity in face of climate-caused disasters:

women empowerment by giving them access to land, education, and information, create community development projects that give more livelihood opportunities to women, and giving them more participation in decision-making (2013, p.81).

But would it be possible to implement these strategies if the low consideration of women in the culture persists? Are men in Bangladesh ready to provide more of those strategies to women, stopping cultural, racial, and ethnical discrimination and injustice? These questions reinforce the need for developing **reactive barriers removal plan** (RBRP) as part of the adaptation strategy.

### 4.3. Identify and enforce support measures to mitigate maladaptation

Removing the barriers to adaptation is not enough. An adaptation measure can create negative impacts in other sectors even though barriers are removed. Thus, beyond developing measures that have co-benefits, municipalities should also develop support measures to offset the potential negative impacts of adaptation measures to minimize maladaptation.

If negative impacts are not tackled, adaptation measures that has created negative impacts would themselves become barriers to adaptive capacity, resilience, and development in other sectors.

Since Mexico has the potential to enforce strategies with law, integrating support measures in the country's public policies is an appropriate way to ensure support measures are set up.

### 4.4. Elaborate an inclusive Social-Stakeholder Engagement strategy (iSSE)

The idea of an integrate social-stakeholder engagement strategy consists of treating social groups as stakeholders when conducting stakeholder mapping, when raising stakeholders' awareness, and when building networking for the stakeholders.

Each strategy applied on the stakeholders would benefit the public and reciprocally. Also, elaborating integrate social-stakeholder engagement fosters collaboration among the stakeholders “within and between municipalities”. This integral strategy has two pillars: inclusion of community groups when mapping stakeholders, and integration of social participative capacity building in the stakeholder engagement strategy.

### 4.4.1. Inclusion of community groups when mapping stakeholders

Social participation should not be separated with stakeholder participation anymore. The mapping of stakeholders should analyze in depth all social groups involved in the management and consumption of water, not just those in the managerial couch, but the grassroots as well. For instance, the stakeholder mapping performed in the PMCC of Pureto Vallarta excludes residents in the list of stakeholders, although they are direct consumers of water.

### 4.4.2. Integration of social participative capacity building in the stakeholder engagement agenda

The Sustainable MAC-Water Framework advocates for the inclusion of social participative capacity building in the agenda of stakeholder engagement strategy at each administrative level because local population are the direct users of water infrastructure and resources.

It is my perspective that if the local population and different indigenous communities do not have enough cognition about the hydrological system or the innovative technology being proposed or other components to understand, social characteristics such as the culture, customs, traditions, or lack of understanding might lead to inefficient assessment of preferences and goals and could present a risk of maladaptation. These might lead to a refusal of certain adaptation measures as well.

When various community groups of the local population are included in the stakeholder engagement strategy, they can benefit from the capacity building, information dissemination, and awareness raising intended for the stakeholders. Also, the gaps between the leaders and the population could be reduced, and inter-municipal and municipal-resident collaborations would be more likely harmonized.

Finally, even the strategies to build the participative capacity of all stakeholders should be figured out and implemented together along with the elaboration and the implementation of the adaptation plan.

### 4.5. Establish transparent leadership

#### 4.5.1. Goodwill for transparency and public dissemination of projects

The case study on Atenco leads to the conclusion that local population are not yet ready for inter-municipal collaboration. To re-build trust, I suggest the mayor and city council decide to demonstrate their goodwill first by informing the residents what is really going on at the wells, second by declaring publicly that they will change their decision-making process by taking new resolutions such as transparency and consultation of the community's preferences before taking actions.

#### 4.5.2. Detailed stakeholder mapping

Transparency cannot be ensured without knowing who are involved in the water management and use. When the society know who the actors are, it could be easier to track the responsible for the water transfer from one well to another one outside a municipality. Also, a lack of transparency infringes social participation which cannot be inclusive enough without a detailed identification of the civil society groups and private sector acting within a municipal boundary and within the human-hydrological system the municipality belongs to. Only the municipal leaders have been identified in the PECC 2014-2018.

## 4.6. Integrate health dimensions in adaptation planning, monitoring and evaluation

The Sustainable MAC-Water framework proposes to include health dimension as part of the integral analysis of adaptation measures during the decision-making process and for evaluation purpose. The quality and quantity of available drinking water and sanitation-purpose water are directly impacting human health. The work of Riojas-Rodríguez et al. reports that below five-year-child mortality rate reaches 15.5%, and this rate is 12.7% for babies under 1 year in Mexico (2018, p.282). Children are dying from intestinal infections, acute respiratory tract infections (ARIs), malnutrition rate of 10% in urban areas and 19% in rural areas, dengue, chikunguya, asthma, pneumonia, any other diseases, and lack of hygiene (p.282). Riojas-Rodríguez et al. also inform that heat rise has caused 393 deaths in Mexico during 2002-2010, and that number will double in 20 years says the World Meteorological Organization (WMO). Despite these significant public health issues, the inclusion of the health dimension in adaptation efforts is still weak in Mexico (Riojas-Rodríguez et al., 2018). By adding health indicators in designing and assessing adaptation capacity, this Sustainable MAC-Water framework strengthens the adaptive capacity of the whole system.

## 4.7. Indicators to assess the sustainability of adaptive capacity

The Sustainable MAC framework suggests indicators of the sustainability of adaptive capacity.

The indicators of adaptive capacity used by Monterroso et al., (2014) to map the degree of adaptive capacity per municipality seen in Figure 8 include 16 variables from four dimensions listed in the following table:

*Table 1: Indicators used for adaptive capacity mapping in Mexico*

| Dimension | Variables |
|---|---|
| Human Capital | % change in population by 2030<br>% of population in the municipality that can read<br>% of 5- to 14-year-old population that attend school<br>% of total literate population in the municipality |
| Social capital | % of organized production units in a municipality<br>% of production units that do not have litigation for the land in a municipality<br>% of production units that indicated not having a lack of training in a municipality<br>% of production units that indicated not having trouble producing capital in a municipality |
| Financial Capital | % of production units that indicated not having difficulty to access credits in a municipality<br>% of production units in the municipality that receive remittances from foreign countries<br>% of production units in a municipality that reported having savings<br>% of production units in a municipality that reported having credit<br>% of population that receives more than 2-month minimum salary<br>Percentage change in GDP from 2000 to projected 2030 |
| Natural capital | Relationship of municipal area with forest or jungle<br>Reforested hectares in the municipality in 2005 |

Source: Monterroso, 2014

However, these indicators need additional indicators of the adaptive capacity of the system. Even though Atenco, for example, is classified among those having high degree of adaptive capacity (Figure 7), the case study on Atenco reveals that this rural municipality does not have a PMCC yet and residents were not included as stakeholders that govern climate adaptation with municipal leaders. These two only can indicate that Atenco does not have enough adaptive capacity to transform its water vulnerability to climate change. Therefore, there is still a need to improve adaptive capacity indicators.

The indicators of sustainability of adaptive capacity presented in Table 2 are the results of the evaluation performed across this paper. They can be used to appreciate how sustainable adaptive capacity is to guarantee that adaptive capacity actions for the municipalities, their actors, their water resources, and their infrastructure multiply without maladaptation.

These indicators can be used as additional indicators when assessing adaptive capacity during the planification, implementation, and assessment stage.

*Table 2: Sustainable Adaptive Capacity indicators*

| **Planification stage** | **Implementation stage** | **Evaluation stage** |
|---|---|---|
| Inclusion of community groups in the stakeholder mapping | Participation of all stakeholders | Participation of all stakeholders |
| Existence of Reactive Barrier Removal Plan | Outputs of the barrier removal plan | Outcomes of the barrier removal plan |
| Existence of support measures | - Enforcement of support measures<br>- Outputs of the support measures | - Outcomes of the support measures<br>- Negative impacts of the adaptation measures |
| Existence of a leadership transparency strategy | Output of the transparency strategy | Index of transparency |
| Health indices attributable to climate change | Health indices attributable to climate change | Health indices attributable to climate change |

## CONCLUSION

The *Sustainable Municipal Adaptive Capacity framework for Water* (Sustainable-MAC-Water framework) created in this paper is a tool that facilitates the building of adaptive capacity for the highly vulnerable municipalities and water systems in Mexico but also elsewhere, in way that maladaptation is not created, and adaptive capacity is itself resilient.

Compared to the existing adaptive capacity frameworks, the Sustainable MAC-Water framework ensures that adaptive capacity is built with minimum risk of maladaptation because it suggests additional aspects to the governmental adaptation plan as follows:

1- It recommends the establishment of a **Reactive Barriers Removal Plan (RBRP)** along with the Sustainable MAC-Water plan.
2- It recommends the identification and implementation of **support measures** with all stakeholders in reaction to the negative impacts of the adaptive measures.
3- It suggests the integration of social participation in stakeholder participation strategy by elaborating an **Inclusive Social-Stakeholder Engagement Strategy (iSSE)**
4- It requires **transparent leadership**
5- **Health dimension** is incorporated in the indicators to help the decision-making on the adaptive capacity measures and to guide conducting monitoring and evaluation plans.
6- **Sustainable Adaptive Capacity Indicators**

These components make this Sustainable MAC-Water framework sustainable, transformational, and hence providing municipalities with the potential to strengthen their resilience to climate change.

However, since the proposal to establish RBRP has been established with the hypothesis that barrier mitigation is less emphasized in the adaptation literature, further time is necessary to navigate the internet about adaptation barrier removal plans, and to validate if they are mostly missing.

Also, the wish to incorporate the biodiversity aspect could not be satisfied. The Sustainable MAC framework should include this aspect in the future because Ecosystem-based adaptation is among the core adaptation strategies of Mexico and the depletion of water resources have important impacts on the biodiversity too.

Moreover, additional reviews are necessary to test and improve this framework with on-the-ground applications. Therefore, in the future, this Sustainable MAC-Water framework should be applied to Mexican municipalities located in the highlighted watersheds in Figure 4, to those which have not reported traces of responses to adapt to the projected impacts of climate change, and those among the most vulnerable in Figure 5. Such cases studies could lead to the amelioration and validation of the Sustainable MAC-Water framework. The validation can lead to the use of the adjusted framework on other municipalities and other sectors in Mexico and other countries. When applied to other sectors and administrative level, the components specific to water resource management at the municipal level will have to be replaced, though. Those applications will reveal what works and what does not and will help adjust the elements of the framework based on experience.

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