Climate's Long-term Impacts on Mexico's City Urban Infrastructure

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1. Introduction

The most adverse effects of climate change are likely to take place in cities where people, resources and infrastructure concentrate[1] . Among urban areas, large cities, with complex urban infrastructure systems problems and ongoing environmental problems are at the mercy of these additional changes if careful planning is not done on time and proper investments put in place.

Mexico City is a relevant case study for the climate change community to understand impacts on a large, complex city. The greater metropolitan area, Mexico City Metropolitan Area (MCMA), has approximately 20 million people, over four million vehicles, very intricate systems of energy and water supply, and transportation infrastructure that may be highly vulnerable to climate change impacts. This is because it may face a range from relatively mild to extreme weather events. As of now, it is already under significant stress due to population growth and density and growing environmental problems. Additionally, investment has not been keeping up with requirements of capital to upgrade infrastructure, or to at least maintain, these systems.

Thus, the key issues raised by this case study that may provide important lessons for other regions of the world include the potential problems raised by the compounding of pressing environmental problems and the expected effects of climate change on the aging infrastructure.

2. Structure of the city

According to the Third National Communication presented by Mexico before the United Nations Convention for Climate Change in 2006, and the National Emissions Inventory 1990-2002 produced shortly after, Mexico contributes with 1.5per cent of global emissions of greenhouse gases, an estimate of a little over 643 million tons of carbon dioxide equivalent (tCO2e). Therefore, it is the 12th emitter worldwide[2]. About 25per cent of the country´s economic activity and population is concentrated in Mexico City.

Mexico City Metropolitan Area (MCMA) expands throughout Distrito Federal and part of Estado de México, in the center of the country. It is located at approximately 2,240 meters above sea level and covers an extension of 4,979 km2. It holds approximately 18 million people; 8.6 million live in Distrito Federal and the rest in Estado de México. It has a high population density of 3,584 persons/ km2 that is among the highest in the world, and a lively lifestyle. Even though it has among the highest GDP per capita in the country, it is also among the cities with more income inequality. Additionally, for 2000 in MCMA 13.1per cent of its population lived under food poverty (i.e. with not enough money to purchase minimum food requirements), 22.8per cent under poverty of capabilities (not being able to cover health and education needs) and 54.7per cent under poverty of patrimony (not having access to clothing, housing, and the ability to bequeath human capital to future generations)[3].

1 World Bank 2009

2 INE 2006

3 Alvarez et al 2006

Mexico City alone emits about 9per cent of the country´s overall emissions. Even though the largest share of the population is in the counties of Estado de México, 61per cent of emissions come from Distrito Federal, i.e. 36.2 million tCO2e. However, these emissions may be quite underestimated due to the "carbon-leakage" kind of emissions derived from burning 3.4 million barrels of oil a year to bring water to Mexico City as will be discussed below.

3. Pressing environmental problems

Independently of the expected effects from climate change, Mexico City has a complex set of goals. First, it has to make sure that the wellbeing of its citizens is attained and protected. Second, it has to ensure access to its citizens to environmental quality. This can be done mainly through the conservation and protection of the natural environment and by managing natural resources sustainably and efficiently.

At the same time, the city is growing, both in population and spatially. And even though economically and socially this city has the highest living standards of the country on an average basis, it also has among the greatest disparities in income and opportunities. This then is an added challenge to environmental policymakers because a vast large amount of resources have to be used to attain minimum living standards and reasonable social and economic indicators.

3.1. Urban growth

The city is still growing, both in population and in size. When leaving the city basically in any direction, it is easy to observe its expansion. From an environmental standpoint, urban sprawl causes increase in the demand for different types of infrastructure and adds strain on the existing ones. Mexico City is growing more on the side of Estado de Mexico than in Distrito Federal. This may be due to the fact that there is more room available in the former, whereas in Distrito Federal the city is basically going through a re-densification process. By 2020, it has been estimated that there will be more than 22 million inhabitants in the city and 57per cent will reside in Estado de México. With this comes the need for new infrastructure. Additionally, due to aging of the infrastructure, maintenance is required for much of the existing one, which is not happening, so tensions because of an outdated infrastructure and a growing need for new resources accumulate.

The city will grow from 1.9 million dwellings in 2000 to anywhere from 2.4 to 2.9 million in 2012[4]. Urban growth can be explained by a lack or urban planning and weakness in enforcing existing regulations. At the end, this can usually be related to higher mobility needs because people tend to live far from their work places because of the price of land and housing. This in itself increases the need of roads and transportation, as well as of providing basic services for the population such as water, sewage, electric power, trash collection, education, public health, recreation and other basic services with the related increase in emissions. Demand for transportation is again a big additional source of energy use and emission. It is estimated that emissions from the transport sector will increase proportionally more than those of other sectors, from 49per cent in 2002 to a range between 53 to 59per cent in 2012, depending on the growth scenario[5]. This in turn will feed into expanding the island effect, because urban

[4] SMA-DF 2006

[5] SMA-DF 2006

expansion leads to land use change and more pavement that together with the burning of additional fuels and an increase in emissions, will increase heat concentration and reduce water capture in an already water-stressed region such as Mexico City.

A related problem to urban sprawl is the constant and growing encroachment of illegal settlements on conservation lands, having an impact on the availability of natural resources as well as on water capture, and on land use that is constantly changing, with the respective deterioration. Additionally, these illegal settlements are usually in disaster prone areas elevating the vulnerability of the city and specific groups both to disasters and eventually to climate change.

3.2. Water availability and the sewage system

Another critical issue, maybe among the most urgent, is water, both at the distribution and sewage collection stages. Supplying 32 m3/second of water into the city, 37 per cent from other basins such as Lerma and Cutzamala, is a great challenge. Bringing water from other basins implies driving it 127 km and elevating it up 1,100 meters, due to the altitude of Mexico City[6]. Once it gets there, due to the outdated infrastructure and theft, 35 per cent of the water in the system is lost during distribution.

In the face of climate change, water demand may increase and its availability may be reduced[7]. Therefore, bringing water to MCMA will add further pressure to its water infrastructure.

The sewage system, on the other hand is quite ineffective and water treatment plants usually lack maintenance and work poorly. Additionally there is no culture of water reuse. Moreover, rain water and raw sewage go through the same drainage system, polluting the former and making it totally unusable for other needs. Finally, the database of water users is outdated and incomplete, so there is a limited recovery of user charges and those that pay do so at very subsidized prices.

In summary, there is a pressing need to revise the entire water system, from water capture and distribution to sewage recovery and maintenance. Operation and the scarcity cost of water should be reflected to final consumption through market pricing. This may help to avoid overexploitation, reduce pollution, and increase water availability for the city through the build up of water infrastructure and the implementation of water saving programs.

3.3. Solid Waste

Disposal of solid waste is closely related to population growth and to the current lifestyle. Distrito Federal generates 12,500 tons of residues a day and Estado de México at least the same amount. Of these residues for Distrito Federal 60per cent are inorganic and 40per cent organic. Confining them in adequate landfills is a true challenge because of the problems related to collection, transportation and final disposal of those residues. Additionally, landfills generate greenhouse gas emissions and effluents leak into the water table, polluting scarce water resources.

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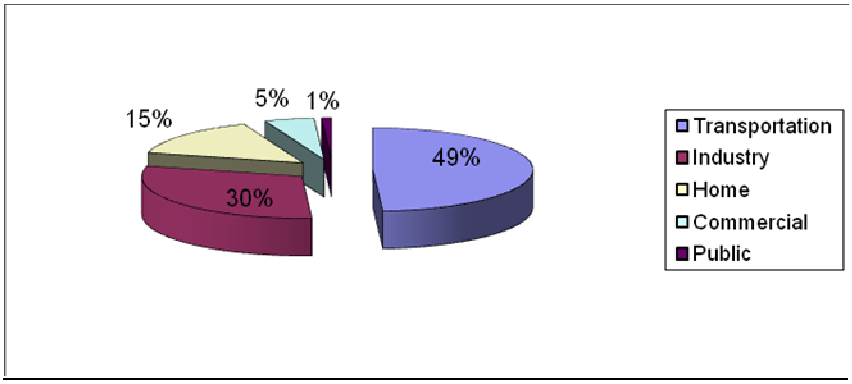
6 GDF 2002

7 SMA-DF 2008

3.4. Sectoral emissions and trends

Between 1996 and 2000 energy consumption in Mexico City increased from 583 PJ to 626 PJ, growing in 7.4per cent during the period. The city consumed 14per cent of all national fuels and 16per cent of all electric power. The largest consumer in 2000 in MCMA was definitely transportation, with 49per cent, followed by the industrial and the residential sectors (see Figure 1)[8].

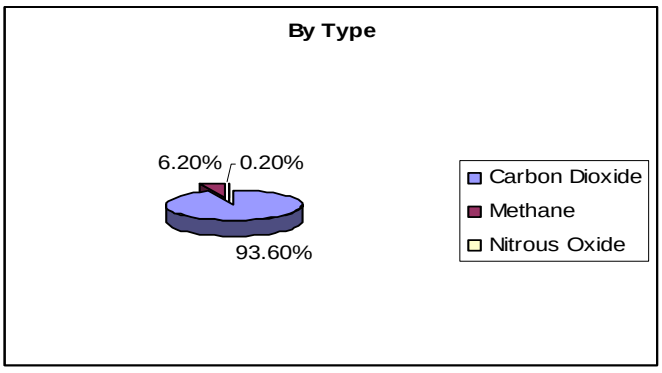
Figure 1: Energy consumption by sector for MCMA in 2000



Source: SMA-DF 2006.

Economic activity generates different types of greenhouse emissions. By and large, carbon dioxide is the most important emission (93 per cent), followed by methane (6 per cent). This pattern of emissions is a clear result of urban life, where most emissions come from energy use (93 per cent) and the generation of solid waste (6 per cent).

Figure 2: Emissions by type of GHG and by source in MCMA in 2000



Source: SMA-DF 2006

[8] SMA-DF 2008

Several studies have been undertaken to forecast future energy use and emissions in the near term (i.e. up to 2012). In terms of expected trends of emissions, the relative participation of the different sectors will remain the same as now. However, energy consumption is expected to grow anything from 13per cent under a low growth scenario to 26per cent under medium growth and 41 per cent under high growth, all with respect to 2000. Emissions, on the other hand will grow accordingly and will be anywhere from 59 to 80 million tCO2e, as compared to 36.2 million tCO2e in 2002[9].

4. Expected effects of climate change on Mexico City Metropolitan Area

Mexico City is vulnerable to climate change because of the physical threats it faces as well as its socioeconomic factors. In terms of the physical conditions that may become a significant problem is the fact that the city is located in a closed basin, artificially drained, that makes it especially vulnerable to changes in precipitation patterns. Socioeconomic conditions that may favor vulnerability are illegal settlements, wide-spread poverty and a skewed income distribution.

Added to those initial constraints, climate change is expected to have four main effects on Mexico City. First, it will increase average temperature leading to more extremely hot days and spells; second it will increase extremely low temperatures and reduce cold waves; third there will be more flashfloods; and fourth drought periods will increase in the summer months[10]. These four factors may have different and simultaneous outcomes, as discussed below.

4.1. Hotter days and more heat waves

If maximum temperatures become higher, with warmer days and more frequent heat waves, there will be an increase in the expected mortality and morbidity rates among the higher age cohorts as well as among the urban poor, and an increase in power demand for air conditioning or other cooling devices[11]. This in turn may lead to specific infrastructure being under stress, particularly power systems. Additionally, under this scenario Mexico City is highly vulnerable due to the relation between high temperature, increased evapo-transpiration, reduction in the water bodies, and a lower rate of infiltration towards water tables.

This increase in temperature has already been felt in the city, reaching temperatures between 33 and 35°C. On one hand, the elders´ cohort has been growing from 5.1per cent of the population in 1995 to 6.8 per cent in 2006. This age group is now at a greater health risk due to higher odds of getting affected through heat waves[12]. This age group is expected to continue growing in the near and long term due to the normal trend of population aging. Thus, a larger share of the population will be exposed, since they are especially sensitive to heat waves as seen in 2003 in Europe[13]. On the other hand, this increase in temperatures is also likely to affect the rest of the population in Mexico City because people do not usually have air conditioning and cooling systems, and because buildings are not designed to face extreme temperatures. When income is high enough, the power system may fall under severe stress due to an increased use of air conditioning. Finally, health related problems may arise because

9 SMA-DF 2006

10 SMA-DF 2006

11 IPCC 2001

12 INEGI 1997, 2006

13 Martinez et al 2004

food becomes poisonous more easily due to extreme heat[14]. This may eventually further stress the public health system.

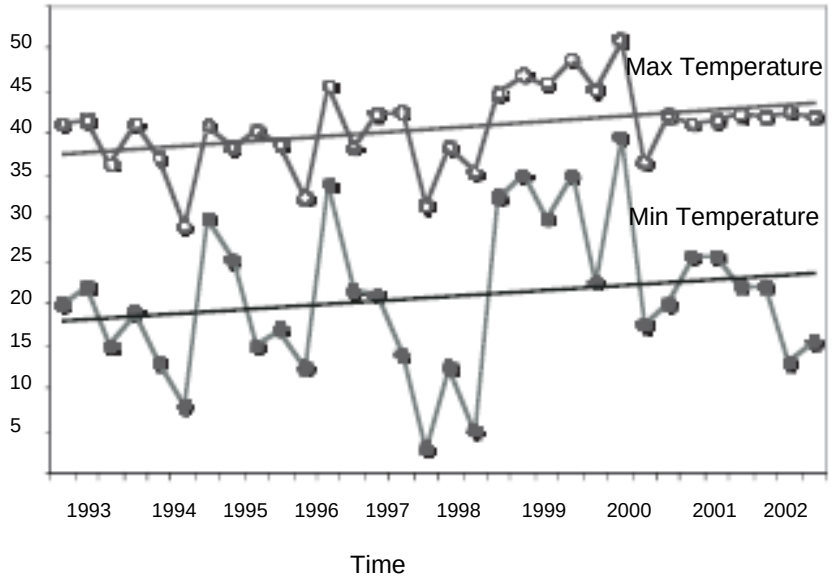
4.2. Fewer cooler days and more mosquitoes

Minimum temperatures are expected to be higher, implying less cold days, freezes, and cold waves. This may lead to a reduction of human cold-related morbidity and mortality. However this may favor vector and bacteria-related diseases in the city[15].

This condition is now present in Mexico City, where minimum temperatures seldom fall below 0°C. Additionally, extremely low temperatures are less frequent, as shown in Figure 3. This may increase living standards for most part of the population and cut back on heating needs, and thus on fuel and demand for electricity for heating purposes.

On the other hand, mosquitoes and plagues do much better under higher temperatures during a larger part of the year, so they may proliferate and disseminate vector diseases in Mexico City that was previously free from these types of illnesses[16]. This again, may add pressure on the public health system.

Figure 3: Maximum and minimum temperatures in Distrito Federal, degrees Celsius (March, April and May 1993 to 2002)



Source: SMA-DF 2006

4.3. More flashfloods

Climate change tends to increase the amount of moisture retained at one moment in the atmosphere and therefore the amount of rain poured in one single episode. This leads to

[14] SMA-DF 2006

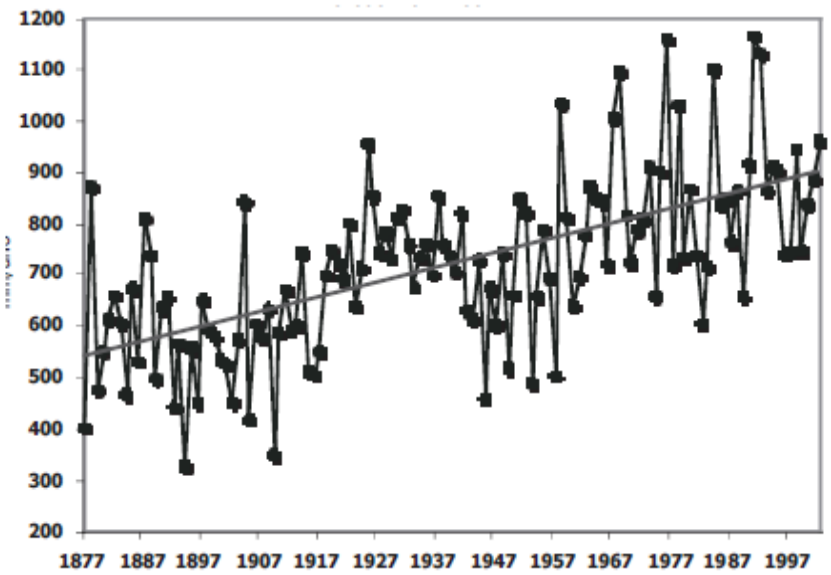
[15] IPCC 2001

[16] SMA-DF 2006

flooding and landslides, and as a byproduct, to soil erosion through water runoff. This additional water from floods may be thought of as an added source that could be captured through infiltration, but given the large amount of water and the high rate at which it concentrates at one point, it usually leads to disasters, where both the government and private insurance companies have to intervene[17].

Precipitation in Mexico City increased from 600mm/year in the early 20th century to over 900 towards the end of the century, as shown in Figure 4. Higher precipitation is associated with an increased frequency of extreme events with more than 30 mm/hr (or flashfloods). Flashfloods have increased from 1 or 2 per year at the beginning of the 20th century to 6 or 7 towards the end, as can be seen from Figure 5.

Figure 4: Annual Rainfall in Distrito Federal, 1877-1997, (mm per year)



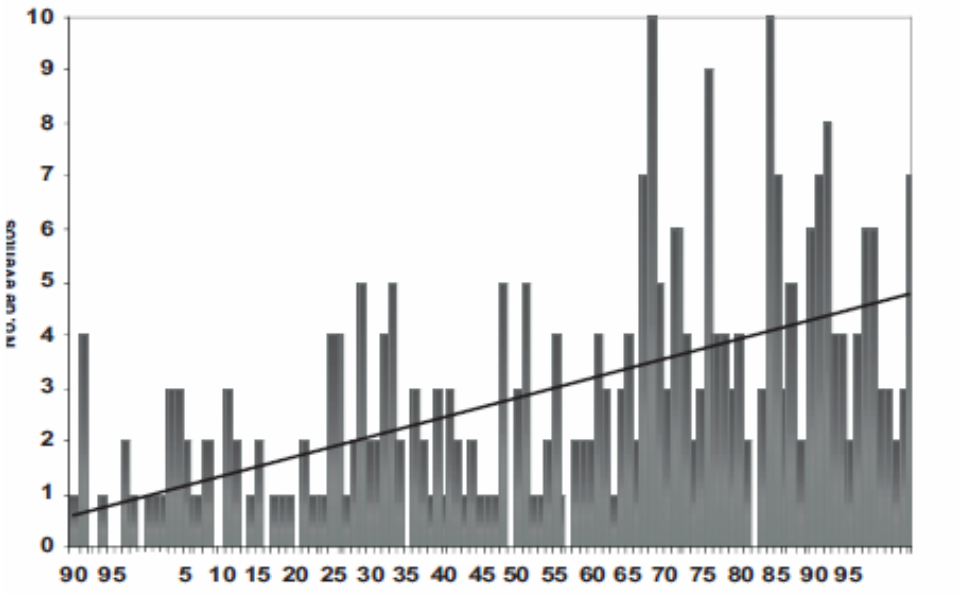
Source: SMA-DF 2006

Particularly the physical characteristics of the Valley of Mexico where the city is located as well as illegal settlements with poor housing in risk-prone areas make hydro-meteorological phenomena a constant threat to the city. Within the Distrito Federal alone, 24 thousand people are highly vulnerable to these water-related extreme events (SMA-DF, 2006). No data is available but at least an equal amount is at risk in Estado de México. Landslides happen close to the areas where water from floods typically runs through and these waterways often collect materials and trash that increase the threat to the population and eventually block the way for water. Even though heavy rain occurs in the west of the city, floods take place in the east and south, given the way water flows and the very precarious infrastructure. At the end of the day, 65per cent of these floods are due to insufficient sewage, 30per cent to flooding of roadways, and 5per cent are due to housing infrastructure. These flashfloods are expected to increase under climate change. For example, in August 2, 2006 there was a rainfall of 50.4 mm in only 36 minutes, causing severe floods in the south and west of the city[18].

[17] IPCC 2001

[18] SMA-DF 2006

Figure 5: Extreme rainfall events in Distrito Federal: 1890-2003 (number of events per year)



Source: SMA-DF 2008

4.4. Extended Summer Drought

The interior of the continental regions of medium latitude are expected to be affected by drought, causing a reduction in crop yields, damages to the foundation of buildings due to soil contraction, a reduction in the quantity and quality of water resources, and a greater risk of forest fires[19].

Migration from barren rural lands is maybe among one of the expected results from climate change that in the case of Mexico is expected due to increased temperature and drought. This may generate another important wave of rural-urban migration, so these people will probably move to the bigger cities, if not internationally, to protect themselves from the strains caused by climate change directly on their livelihood.

Conservation land within the city already faces water shortages, so climate change will most likely affect the "ejidos" (i.e. common property land) and traditional communities having an agricultural activity in those lands within the city. The fall in the water table is readily verifiable in the sinking of several areas of the city, such as the downtown area, and constant encroachment on conservation land reduces water capture by the aquifer, that together with overexploitation and expected drought will only increase the vulnerability of Mexico City[20].

Additionally it is expected that water management in Mexico City will become worse due to a lack of resources. The current sewage system in the city makes it unfeasible that the water

[19] IPCC 2001

[20] Perló and González 2005, Carabias and Landa 2005, Legorreta 2005

from the flashfloods is taken advantage of given that raw sewage and rain water pass through the same pipelines.

On the other hand, the dry period is between winter and summer. The lack of humidity in the soil, high temperatures and strong winds increase the risk of forest fires in conservation lands, particularly when spring comes after a dry winter, as in the case of El Niño. Additionally "slash-and-burn" agricultural practices that still take place there contribute to forest fires and deforestation.

Finally, air quality is likely to suffer when there are higher temperatures and therefore affect human health: drought, late rain and higher solar radiation may increase ground-level ozone and total suspended particles, leading to higher levels of respiratory illnesses. These conditions also harms vegetation and cause stress on ecosystems. Moreover, the heat island effect has altered the climate of the city mainly through higher temperatures and changes in the hydrological cycle. This effect itself may be of a great magnitude and maybe higher than that of climate change, but it has not been acknowledged as a threat to the population[21].

These threats that arise due to climate change are summarized in Table 1 in the column of expected impacts, and broad adaptation options are described in the last column of this table. The latter will be discussed in section 6.

Table 1. Adapting to the effect of climate change in Distrito Federal

Sector	Expected Impacts	Adaptation Measures
Water	Reduction in the quantity and quality of water resources	Develop policies to protect aquifers, leading to sustainable management
	Problems with the maintenance of water bodies and infiltration of pollutants to groundwater	
Agriculture, Cattle and Food	Decreased crop yields, especially in rain-fed lands	Policy promoting a sustainable use of natural resources and biodiversity
	Increased heat stress on cattle	Policy promoting an equitable and sustainable rural development
Land Ecosystems and Water	Increased risk of forest fire	Fire protection program and stopping urban sprawl
	Increased soil erosion and flood runoff	Incentives to maintain environmental services
Human Settlements, Energy and Industry	Increased damage from floods, landslides and mudslides	Control and management of human settlements in risk-prone areas
	Problems with energy, decreased hydropower in drought-prone regions	Integrated protection policy

[21] SMA-DF 2006

		Promote energy savings and efficiency
	Subsidence and cracking due mainly to loss of groundwater level	Increase in infrastructure and sustainable management of green areas
Insurance and Financial Services	Material and heat hazards	Public and private insurance
	Increased incidence of death and severe illness in elderly urban population	Monitoring of disease
	Increased number of people exposed to vector-borne diseases, as well as water and waste-related sickness	Surveillance and control programs in public health
	Decreased air quality due to increase in temperature	Solid waste policy
		Air quality program (MCMA): 2002-2010
Health	Food hygine	Environmental policy for industry
		Environmental education
		Environmental policies
Information and R&D		Integrating environmental actions and programs
Source: SMA-DF 2006		

5. Compounding environmental trends and effects of climate change

Mexico City is highly vulnerable to extreme conditions imposed by climate change, be they higher temperatures, flashfloods or drought, or an increase in vector-borne disease. Its urban infrastructure is definitely not prepared to respond to these changes. Moreover, its natural environment may not have the added capacity to absorb more pressure. Unfortunately, little of this is documented and quantified. As in most developing countries, resources are not readily available and the existing resources are devoted to immediate action and short-term projects rather than to planning for the long term, and this issue of the effects of climate change is long-term.

In summary, Mexico City´s urban infrastructure is vulnerable to climate change in many ways. First and foremost, the entire water system is outdated and insufficient, both for clean water distribution and for sewage and rain water collection. Additionally, the supply of clean water in the city is not enough, as can be seen from the common water shortages in several parts of the city. Thus more water will be brought from even farther places, increasing the costs even more. And if prices remain subsidized as of now, and the database of water users is not brought up to date, then there will be a significant scarcity of resources to improve the water system.

Of the very costly water that is brought to the city for consumption, roughly one third is lost during distribution. There are at least two ways that climate change will compound these effects on the water system. First, less water will be available due to drought and higher temperatures. Second, less water capture will contribute to reduce water tables and, in turn, favor the sinking of land on which water pipelines lie, causing it to break and therefore

causing more water loss during distribution and the contamination of clean water with sewage from broken pipelines. The sinking of parts of the city, again, may cause severe cracks to the streets and roads system, affecting from pavement, houses and buildings to the subway system.

On the other hand, the sewage system has to be modernized and new separate pipelines built for rain water. If not, flashfloods may cause the sewage system to break apart with obvious damage to other infrastructure such as housing and eventually to health. Lower water quality in itself, regardless of sewage contamination, is one of the expected results from climate change, so compounding this with effluents from the sewage system and landfills, and more vector diseases that are also expected to result from climate change, will create an adverse epidemiological environment that will put added pressure on the already strained public health system.

Extreme temperatures, particularly a higher frequency of hotter days, will increase the demand for electricity for air conditioning. Additionally, given that buildings are not weather-proof then cooling needs will expand. If people do not have access to cooling systems, this may cause great discomfort lowering their wellbeing, which is very hard to measure.

Another important effect from climate change is a reduction in food production elsewhere in the country and within conservation lands in the city. This will imply higher food prices in MCMA. This may cause social unrest in significant sectors of the population that is already under poverty. Unequal income distribution, on the other hand, tends to exacerbate these effects. Eventually, even political instability may arise. This may be exacerbated by migration from other parts of the country to the city once people are unable to produce on their land. Some studies show that by 2050 about 60per cent of the land will not be suitable for growing corn, which is a crop that is relatively well suited to face high temperatures and water shortages[22]. Producers of other crops may be affected even more. Many of corn farmers are subsistence producers, i.e. they consume their entire production, so if they have nothing to consume they might as well migrate to cities where they perceive that more opportunities are available. And they will probably continue their migration abroad. The fact that they migrate to urban areas, namely Mexico City, will increase congestion of urban infrastructure and services, as well as urban sprawl and illegal settlements that in turn increase vulnerability. This in turn reduces the amount of conservation land available and more public resources are distracted to provide services to migrants, leaving fewer resources to improve and maintain existing infrastructure and to catch up with the lags.

6. Public policies for adaptation

Local authorities face the urgent need to increase adaptation capacity to climate change and therefore reduce the vulnerability of its people and its infrastructure. However, as can be seen from the above analysis, most studies relate to the impact that climate change is expected to have on climatic conditions and therefore the challenges that MCMA faces, rather than the way climate change may affect its environmental capacity and infrastructure. Thus, looking at the main challenges that climate change imposes on Mexico City Metropolitan area, the adaptation policies that the local authorities have crafted are listed in Table 1. The table shows that climate change related risks must be included in the design of policies to address development, and that will in turn reduce vulnerability. However, these policies seem rather general and no specific policies have yet been designed.

[22] SEMARNAP 1997

Ultimately, the response to climate change impacts within cities is an issue of urban governance. What was found in the literature usually covered only Distrito Federal, or at least more in depth. Estado de México, that holds more than half of the population of Mexico City, is not always included in the available analyses. This is a constant issue, where there two federal entities seldom cooperate, sometimes because they are ruled by different parties, sometimes because of interest groups on both sides. The fact of the matter is that the difficulty to have them work together leads to poor planning and bad implementation of metropolitan urban policies, even though there are some real exemptions to this issue like the newly inaugurated metro that goes from Distrito Federal to Estado de México.

7. Conclusions and further research

Climate change will represent an additional factor that will eventually put pressure on the existing infrastructure-related problems in Mexico City. It will increase the challenge posed by a growing population, and further emphasize strains on natural resources and feed back the vicious cycle of poverty and marginalization of vulnerable groups.

Infrastructure in Mexico City is deteriorating. Limited resources have been put into maintenance and not enough has been directed to build new ones, at least not ones required to face climate change. Large investments have been made in building new roads and bridges, and some major repairs are being done to the water system to enable to meet present needs, but no fundamental changes have been done to improve it to face climate change.

Prior to any further investment, serious planning is required in order to have some urban development plan for the greater metropolitan area that responds to future scenarios of climate change, making an accurate assessment of the infrastructure, its lags and future needs. Planning should also include a clear description of the type of climate change-resistant infrastructure that needs to be developed. This seems like a straight-forward idea, but while carrying out a literature review for this report, no clear diagnosis has been found on the expected effects of climate change on urban infrastructure. Plenty was found on the expected effects of climate change, but no efforts have been found on estimating the costs that will be imposed on infrastructure and no planning has been done to overcome this infrastructure vulnerability.

The vulnerability that Mexico City Metropolitan Area faces is huge. The city was built and has grown more for political stability reasons than on the basis of any sort of urban development plan, and with very short term objectives. But climate change is now in the radar of social awareness and it is increasingly evident to its population that the city is not sustainable by any standards, let alone climate change, and that there is a constant need for better infrastructure. People also feel that these lags place significant parts of the city at risk, and this may eventually lead to political instability.

This sustainability and economic crisis may also give rise to social participation if the government of the greater metropolitan area is able to direct its citizens. Under current levels of high unemployment, people may be willing to work on maintenance to existing infrastructure and on conservation land doing reforestation or cleaning it up to reduce the risk of forest fires. Eventually a large population that is aware of the risks it faces and understands the opportunities that the government creates may choose to participate productively strengthening the urban infrastructure to its own benefit.

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