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THE DIRECT COSTS OF CLIMATE CHANGE DAMAGES AND ITS IMPORTANCE IN THE GDP: AN ANALYSIS FOR MEXICO (2003 – 2019)

KARLA FERNANDA MACÍAS TORRES

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ASESOR:

MTRO. ALFONSO MERCADO GARCÍA

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ABSTRACT

Climate change is a concerning and a real challenge driven by greenhouse gas emissions (GHG). The concentration of GHG in the atmosphere alter climate systems, leading to global warming which threatens other systems -economic, social, political, and cultural- by causing damages. Specifically, there is an extensive discussion about the harmful and significant impacts that climate change could have on economic indicators, such as GDP, due to capital and infrastructure losses that are associated with price increases and interruptions in production.

This work's main objective is to analyze the direct costs of climate change damage in Mexico during the first two decades of the 21st century since it has been declared an extremely vulnerable country. The specific aims are to estimate the direct damage costs of climate change in Mexico, and to study the relative importance of these costs in Mexico's GDP, its trend, and structure. For this, five types of damage caused by global warming were identified: environmental deterioration, tropical cyclones, other extreme weather events, losses in agricultural production and damage to health.

The sum of the identified direct costs attributable to climate change damages shows a positive trend since 2013, where it started to present accelerated growth rates. Besides, the annual average cost of climate change damage is $705 billion Mexican pesos. However, direct costs of climate change damage as a percentage of GDP have tended to decline during the reported period, with a reported annual average of 4.5%. Also, this work shows that the direct damages of climate change have concentrated in a particular type of damage, which is environmental degradation, predominantly air pollution.

CONTENTS

INTRODUCTION

Climate change is a concerning and real challenge for the world economy due to its threat to essential resources: water, food, health, land, and the environment (Stern, 2007). Following the World Wildlife Fund (WWF, n.d.), climate change is attributed to natural and anthropogenic causes. The latter are due to human activities that alter atmospheric composition over the years. As evidence, in the last decades, we have registered the most extreme temperatures comparing with preindustrial times. And, at the same time, the period from 1983-2012 has been recorded as the warmest over the last 1400 years (IPCC, 2014).

Greenhouse gas emissions (GHG) have been identified as the main drivers of climate change, and even with international agreements, they have kept their accelerated growth in the last years (World Bank, 2017).[1] With these increases, GHG concentration in the atmosphere rises, leading to alterations in climate systems that are reflected in global warming –the raises in Earth's global average temperature. According to the IPCC (2014), the global average surface temperature shows an increase of 0.85 [0.65 to 1.06] ° C from 1880 to 2012. Furthermore, it is estimated that the sea level has risen by 19 cm, on average, between 1900 and 2010. And it is projected to increase over 44 cm in the next 80 years, implying a threat to coastal areas (Kompas et al., 2018).

All these events linked to climate change have threatened different systems: economic, social, political, and cultural. Specifically, there is an extensive discussion about the harmful and significant impacts that climate change could have on some economic indicators, such as GDP (Stern, 2007; Hallegate, 2017). This could happen due to increases in temperature and extreme natural phenomena, which could trigger adverse events like scarcity of commodities, floods, instability in financial markets, increases in mortality rate, poverty, less productivity, higher inequality rates, and migration (IPCC, 2014; Burke, Hsiang & Miguel, 2015; Hallegate, 2017; Fabris, 2020).

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[1] Carbon dioxide levels are estimated to have increased by at least 60% since 1990, according to World Bank estimates. More information in: https://blogs.worldbank.org/es/opendata/grafica-las-emisiones-de-co2-aumentaron-60-entre-1990-y-2013.

Moreover, it is well known that all these climate change effects are not and will not uniformly be distributed across the world. According to Hallegatte et al. (2010), there is still a problem with some developing countries and their challenge with climate change due to their diminished capacity to rebuild and recover when a natural phenomenon causes a disaster. Also, the time it takes to recover is even more prolonged than in developed countries. For this reason, we can expect that developing countries would be more affected in terms of economic growth than developed ones. Besides, we should consider that different vulnerability to extreme events could also increase inequality between and within countries; this results in a severe problem because inequality is one of the most critical limitations of economic growth and development. If it increases, it could have catastrophic consequences, even more in countries with high inequality rates.

Hereof, this thesis has been decided to analyze Mexico's case since it has been declared an extremely vulnerable country to climate change (SEMARNAT, 2014; OECD, 2013). Also, because some of its effects have begun to be present in some regions. At the same time, all these impacts derived from climate change are expected to trigger damages in two ways, directly or indirectly. The direct ones are derived from variations in climatic systems –increases in temperatures, changes in rain patterns, sea-level increase, ocean acidification, and so on–, that will trigger disturbances in ecosystems; more frequent impacts of extreme weather events with losses in infrastructure, environmental degradation, illnesses, and mortality; new and more frequent diseases due to air and water pollution, and extreme temperatures. Moreover, indirect damages follow the direct ones, similar to a spillover effect which the vulnerability of groups or regions can intensify. This is, more frequent hydrometeorological phenomena will lead to socio-economic disruptions –like inequality and poverty–, as damages in capital or infrastructure increase unemployment and decrease wages. Additionally, further degradation could intensify reductions in crop yields, affecting food security and rising malnutrition levels.

In the same sense, some of these damages generate economic costs, such as capital and infrastructure losses that are associated with prices and interruptions in production. Nonetheless, there are damages for which it is difficult to estimate the loss in monetary values as in biodiversity. But, in this work, we will focus on the direct damages that can be measured in monetary values.

Certainly, Mexico has begun to take action to counteract the adverse effects of climate change. For example, there is a commitment to reduce the emissions for which environmental policies and international agreements were assumed. It has also made annual expenditures of around 0.6% of the GDP to prevent or reduce the environmental damages caused by productive sectors. Nevertheless, it still the first GHG emitter in Latin America, and it is among the first places of carbon emitters worldwide. Thus, it is considered important to analyze the damage costs to design public policies to prevent or minimize vulnerabilities.

Considering the mentioned above and concerned about climate change, specifically its economic damages, the following research questions arise: (1) What are direct costs of climate change damage (DCCCDs) in Mexico?, (2) What is the DCCCDs/GDP ratio in Mexico?, (3) Have the DCCCDs been growing as the DCCCDs/GDP ratio? and (4) Do the DCCCDs in Mexico are concentrated in a specif type of damage?

The hypotheses to be tested are the following: (1) the associated DCCCDs have been growing in Mexico. (2) But, the DCCCDs/GDP ratio has dropped during the reported period. Finally, (3) the DCCCDs are expected to be concentrated in a specific type of damage.

Consequently, this work's main objective is to analyze the direct costs of climate change damage in Mexico. The specific aims are (1) to estimate the direct damage costs of climate change in Mexico, and (2) to study the relative importance of these costs in Mexico's GDP, its trend, and structure.

In order to meet the objectives, the thesis follows a systematic review of different sources, focusing on academic articles, documents, reports from non-governmental organizations, governmental reports, and national accounts. With the available data, an attempt will be made to approximate the direct economic costs derived from climate change. Nevertheless, it must be clarified that the thesis is focused on direct economic damages of climate change, leaving aside those indirectly triggered by the former or those which escape to the market scrutiny, so a possible underestimation in the final impact should be expected. At the same time, some weather events associated with climate change damages have had a historical presence (such as hydrometeorological phenomena), so taking into account all their costs could result in an overestimation.

Lastly, the work is structured as follows. First, a theoretical framework is developed to provide a better understanding of the economic theory of climate change and how these phenomena imply a social cost. Also, the different types of damages and growth limitations are discussed. Then, in the second chapter, we address the problems of climate change in Mexico, how do emissions are rising, and the observable effects. In the third one, the data search process is described, where these data were obtained, and the methodology followed. Later, in chapter four, we discuss the results, and finally the conclusions.

1. THEORETICAL FRAMEWORK

1.1. Climate Change

There is a big difference between climate and weather. While the weather is the set of different conditions of the atmosphere –temperature, winds, snow, storm, rainfall– occurring in a precise moment and region, the climate is the average of these weather patterns persisting over decades. Nevertheless, because of the feedback between both, not only the temperature can alter the climate, but also climate events –like ENSO[2]– affect weather in many regions (UCAR, 2021).

According to the Australian Academy of Science (2013), Climate Change is a persistent change in usual weather patterns, which are observed in statical properties as averages, variations, and extremes. These changes can be attributed to natural processes –as changes in the Sun's radiation– or anthropogenic causes –human activities– that alter Earth's atmospheric composition.

In addition, scientists attribute variations in climate stressors –mainly, rising temperatures– from the last century to human activities, which are degrading terrestrial ecosystems while impacting the atmosphere by expanding the "greenhouse effect" (NASA, 2014; SEMARNAT, 2018; NASA, 2020). They also pointed out that some of the observable effects of climate change on the environment are the loss of sea ice (glaciers and ice sheets), accelerated sea-level rise, and more prolonged and intense heatwaves (NASA, 2020). Simultaneously, all these alterations can result in climate extremes events (droughts, floods, extreme temperatures) that can threaten productive sectors, as agricultural production and food security (IPCC, 2014; SEMARNAT, 2018).

Nevertheless, all the effects of climate change are not and will not be uniformly distributed; some regions will be more severely impacted than others, depending on their capacities to adapt

[2] El Niño Southern Oscillation (ENSO) is composed by cyclical environmental conditions occurring in the equatorial Pacific Ocean, which influence global temperatures and precipitation (NOAA, 2015).

and mitigate emissions worldwide to stop further rises in temperatures (IPCC, 2014; NASA, 2020). Besides, it is almost confident that, although we stop emissions, temperatures will continue to rise in the coming decades due to emissions already carried out by human activities. However, remains uncertain the magnitude of this increase (NASA, 2020).

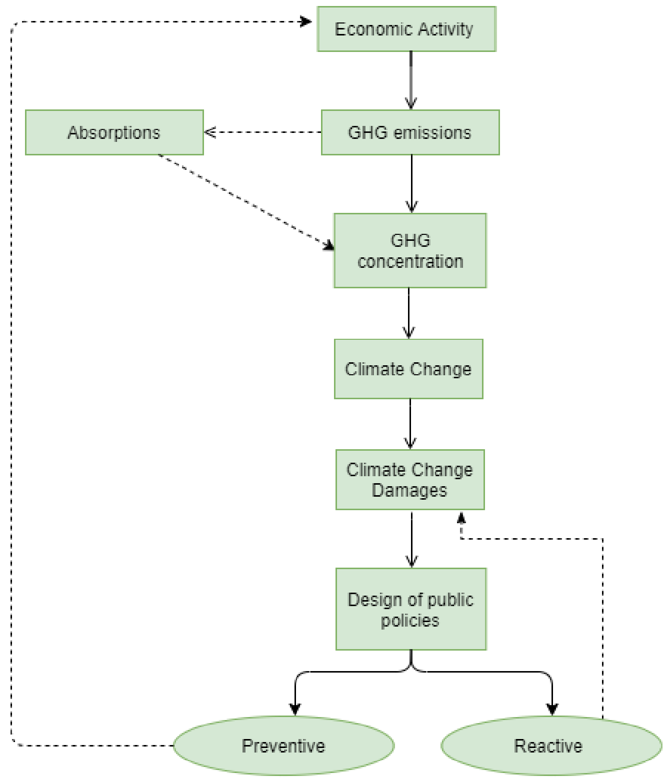
1.2. The leading cause of Climate Change: Greenhouse Gas Emissions

The greenhouse effect is a natural atmospheric phenomenon that keeps Earth habitable, around 30°C warmer than it would be in its absence (Ballesteros & Aristizabal, 2007; Stern, 2007; IPCC, 2014; BGS, 2020).[3] This process arises since Earth's surface absorbs energy from the Sun, and when it tries to send it out to the atmosphere, it is converted into heat. But, at the time this return occurs, greenhouse gases (GHG) absorb much of it because their structure allows it. Then, the heat trapped could go back to Earth's surface, to another GHG molecule, or to space (UCAR, 2021).

Even though the greenhouse effect is a natural process that maintains Earth's temperatures, it is getting stronger as GHG increases its presence in the atmosphere due to anthropogenic emissions related to fossil fuel usage (Stern, 2007). This is triggering accelerated increases in global mean temperatures that have been observed over the last century as a result of accelerated processes of production and consumption. The more common GHG are carbon dioxide (CO_2), methane (CH_4), chlorofluorocarbons (CFC-11 and 12), ozone (O_3), nitrous oxide (N_2O), halons, and water vapor (Ballesteros & Aristizabal, 2007; US EPA, OAR, 2015; SEMARNAT, 2018; UCAR, 2021).

[3] The scientific community confirmed a relation between GHG concentrations on the atmosphere and the global temperature. Also, there is sufficient evidence supporting a strong, consistent, and linear relation between the accumulation of CO_2 emissions and projected changes in temperature until 2100. For more information consult: IPCC, 2014; Ballesteros &F Aristizabal, 2007.

Figure 1.2. Modeling climate change



Source: Perman et al. (2011)

1.3. The efficient level of GHG emissions: Damage and Abatement Costs[4,5,6]

Climate change is considered a negative externality because greenhouse gas emitters are accelerating a phenomenon that will severely impact all systems (economic, political, environmental, and social) without paying. Although there is great uncertainty about the magnitude of these effects, scientific studies claim that they could bring severe and irreparable damages as the temperature continues to rise and while a tipping point is reached. In this regard, measures have been proposed to reduce impacts, such as adaptation and mitigation. Mitigation

[4] Stern (2007). Chapter 2.
[5] Field & Field (2016). Chapter 18.
[6] Perman et al. (2011). Chapter 6.

aims to reduce or stop the increase in the main drivers of climate change, GHG emissions, while adaptation seeks to implement actions that help reduce the vulnerability over these impacts.

Nevertheless, mitigation could be costly depending on the aim of reducing GHG emissions; but it can reduce the negative net social cost arising from these, especially from carbon. That is why many models and research have focused on analyzing the abatement costs and the social costs to find an efficient emission level.

1.3.1. Externalities [7,8,9]

Externalities are one of the several market failures, and they are described as actions that affect others, for which third parties do not pay while benefited –*positive externalities*–, or third parties are not being paid in case of adverse effects –*negative externalities*–. These could lead to inefficient resource allocations.

Environmental damages are negative externalities. As we mentioned, the emissions of GHGs, the main driver of climate change, are triggering social costs by decreasing environmental quality that leads to serious threats to human health and damages in productive sectors –*e.g.,* agriculture. However, the impacts of climate change are independent of the location of emissions, and, at the same time, all countries contribute to the problem because they are emitters. That is why it can be noted that GHG emissions are a negative reciprocal externality. It is also not expected a private solution, so corrective policies should be designed to solve emissions' oversupply.

1.3.2. Damage Costs[10]

Damages, also called costs of emissions, are the set of all the negative impacts that people experience as a result of climate change. These impacts can occur in different ways and vary from one locality to another. However, these damages can often be identified by their type of impact:

[7] Stiglitz (2000). Chapter 9.
[8] Perman et al. (2011). Chapter 4 and 10.
[9] Field & Field (2016). Chapter 4.
[10] Field & Field (2016). Chapter 5.

direct or indirect. The direct ones derive from variations in climatic stressors, leading to more frequent extreme weather events and triggering disruption of ecosystems, environment degradation, infrastructure losses, and human health impacts through injuries, illnesses, and mortality. On the other hand, indirect damages are related to the spillover effects of direct damages. For example, increasingly extreme temperatures will aggravate reductions in food production and price increases, which over time could trigger malnutrition and poverty in rural areas that use agriculture for self-consumption.

In this context, damage functions have been used to identify the intensity of these impacts as they allow us to analyze the behavior of economic and non-economic losses related to the damage factor –extreme weather events, pollution, degradation, etc. However, in this work, we will only focus on direct damage costs from the observable impacts of climate change.

Damage Functions

As emissions increases –leading to variations in climate systems–, damages become greater. Thus, to describe the relationship between GHG emissions and damage, it is used a damage function. For the particular case of pollution derived from GHG emissions, there are two identified damage functions:

- **Emission damage functions:** shows the relationship between the total emissions from a determined group/source and the damages.
- **Ambient damage functions:** shows the relation between the concentration of particular pollutants in the environment and their damages.

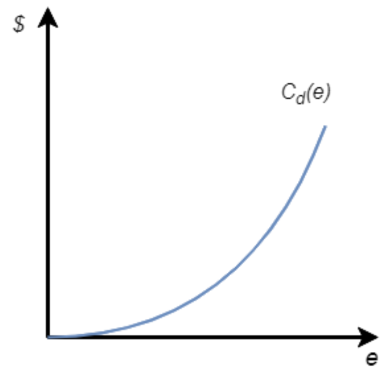
These functions can be used, for model purposes, as **marginal damage functions** to identify better the changes in damages from an additional unit of emission or ambient concentration. The *x*-axis shows the units of emissions in a determined period, and the monetary value of the damages is shown in the vertical axis. Also, the shape of damage functions will depend on the pollutant and specific circumstances.

Thus, damage costs, C_d, dependent only on the magnitude of the emissions, $C_d(e)$, can be specified as:

$$C_d = C_d(e)$$

Where C_d and $C_d{}'$are convex functions.

Figure 1.3.2. Damage function



Source: Field & Field (2016).

1.3.3. Abatement Costs

Reducing emissions can reduce the damages people suffer due to climate change effects. But, reducing emissions can reduce resources used for other purposes or decrease a firm's profit. So, the abatement costs can be considered an additional cost for firms or governments that must reduce emission levels through technological improvements or environmental protection expenses.

To represent the abatement costs, a marginal abatement cost function can be used, $C_a(r)$. Where (r) represents the reductions, but as it depends on emissions, it can be rewritten as $r = e_0 - e$. Here, e_0 is the quantity of emissions without control, while e are the emissions that were made. Thus, the costs of abatement can be represented in the next function:

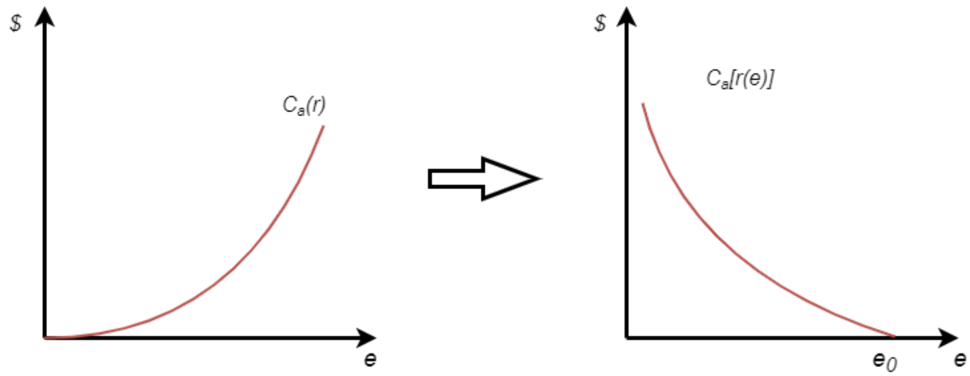
$$C_a = C_a(r)$$

$$C_a = C_a[r(e)]$$

$$C_a = C_a(e_0 - e)$$

Where C_a and $C_a{}'$are convex functions.

Figure 1.3.3. Abatement costs



Source: Field & Field (2016).

1.3.4. The efficient level of emissions

The efficient level of emissions is defined as the level where marginal damage costs and marginal abatement costs are equal. This is the level where both costs can offset one another. Also, the efficient level of emissions is the point that minimizes the total costs of emissions, which is defined as the sum of damage costs, $C_d(e)$, and abatement costs, $C_a(r)$.

$$C_T(e) = C_d(e) + C_a(r)$$

$$\min_e C_T(e) = C_d(e) + C_a(e_0 - e)$$

$$\frac{dC_T}{de} = \frac{dC_d}{de} + \frac{dC_a}{de} = 0$$

$$= \frac{dC_d}{de} + \frac{dC_a}{dr}\frac{dr}{de}$$

$$= \frac{dC_d}{de} + \frac{dC_a}{dr}\frac{d}{de}(e_0 - e)$$

$$= \frac{dC_d}{de} + \frac{dC_a}{dr}(-1)$$

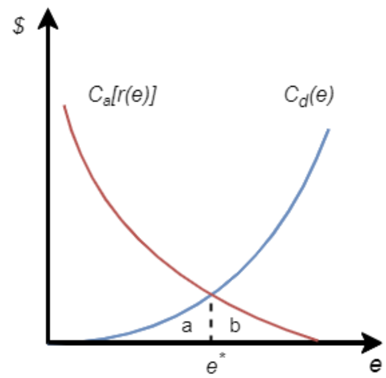
$$= \frac{dC_d}{de} - \frac{dC_a}{dr}$$

$$= C_d' - C_a{}'$$

$$C_d'(e^*) = C_a'(e_0 - e^*)$$

Where $e*$ is called the efficient level of emissions.

Figure 1.3.4. The efficient level of emissions



Source: Field & Field (2016).

Furthermore, the triangular area *a* depicts the total damages when emissions equal $e*$, and *b* depicts the total abatement costs at the same level of emissions. Thus, the sum (*a*+*b*) registers the total social costs, which at $e*$ is the unique point where are minimized.

1.4. Damage Costs of Climate Change

As mentioned above, environmental problems generate costs, which derive from damages to ecosystems, productive sectors, and humans. In this case, climate change is a phenomenon promoted by the acceleration of emissions, which has altered different systems and has increased damages attributed to climatic stressors. Most of the visible damages of climate change are related to impacts from more frequent extreme weather events. Moreover, the costs of these damages can be disaggregated by direct or indirect ones.

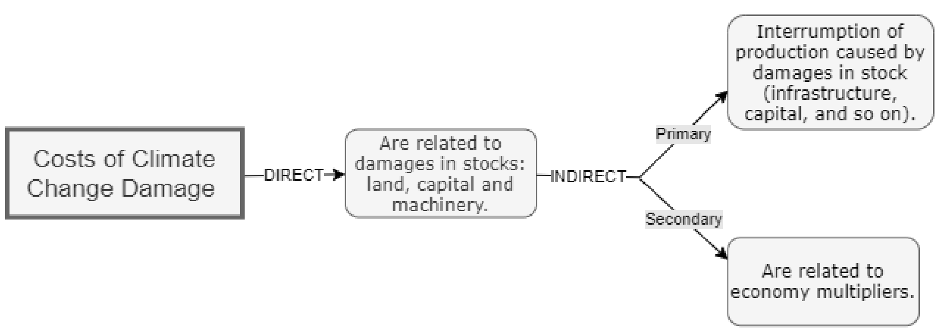
- ## Direct costs

Direct costs are related to the physical damages to the capital stock, industrial and residential infrastructure, losses in agriculture and horticulture, destruction or damage of raw materials, and physical and mental health impacts; all of them recorded as an immediate result of climate change impacts –e.g., more frequent and severe weather events, sea-level rise, new diseases– (Veen, 2004; Lenzen et al. 2019; Mendoza et al. 2019).

- ## Indirect costs

Indirect costs are related to productive restrictions or interruptions of activities due to damages in infrastructure, assets and raw materials, and loss of earnings due to changes in consumption related to damages in roads or marketing infrastructure. Also, there are spillover effects in the short and medium-term, derived from the direct impacts of climate change. It is also mentioned that the magnitude of the indirect costs will depend on the duration of the disruption, the availability of alternative resources for damaged ones, and the possibilities to extend production. (Veen, 2004; Botzen et al., 2019; Lenzen et al., 2019; Mendoza et al., 2019).

Figure 1.4. Climate change damage costs
Conceptual diagram



Source: Veen (2004) & Mendoza et al. (2019).

Having described the two types of costs, it might be easy to assume that the sum of indirect and direct costs will result in the total costs attributed to damages climatic events. However, it has been argued if this amount could lead to double-counting problems because some authors describe productive capital and machinery as instruments that lead to a flow of production and their respective revenues. This implies that disruptions in the productive sectors, treated as indirect costs, would be measuring the same as direct losses (Veen, 2004). But, as this work focus on direct costs, the dispute of the double-counting problem is not foreseen as the main concern.

Furthermore, it is essential to note that economic costs derived from climate change damages are heterogenous, non-linear, and increasing over time (Stern, 2007; Galindo, 2010). This is, the economic costs of climate change are not homogenously distributed; they can differ between regions, periods, and economic activities, sometimes implying benefits or losses (Stern, 2007; Ackerman, 2008; Galindo, 2010). However, it has been pointed out that the poorest countries and populations are the most vulnerable to climate change effects (Stern, 2007). And as the rise in temperatures continues, increases in risks derived from negative impacts would also be awaited at the same level. Nonetheless, it is expected that there will be a tipping point where these costs will increase at higher rates than temperatures (Galindo, 2010). For this reason, it has been suggested that it might be more costly to do nothing than to attempt to counteract the effects through mitigation and adaptation policies (Stern, 2007; Ackerman et al., 2008; Galindo, 2010; SEMARNAT, 2018).

1.4.1. Damage costs by impacts[11]

Some scientific principles point out that impacts will differ by sector or resources, depending on observable increases in temperatures. However, as empirical evidence is still scarce, some authors have been working with studies to find a relationship between the impacts of climate change and increases in temperature, which are derived from rises in GHG emissions (Stern, 2007).

[11] Stern (2007). Chapter 3.

EXTREME WEATHER EVENTS

- *Direct impacts*

Extreme weather events have always existed; they have a historical presence and are responsible for severe damages that have impacted human systems and ecosystems. They also cause direct economic costs due to losses and damages in goods, services, and infrastructure, implying a threat to economic sectors (Lindell et al., 2003). But climate change is altering these events' frequency and intensity, increasing the vulnerability to its effects and, hence, its economic costs (IPCC, 2014).

According to the IPCC (2014), climate change increases the risk of extreme weather events by amplifying its two components: the probability of adverse events occurring and the impact or consequences of those events. This means that the frequency of weather-related events such as extreme temperatures and variations in precipitation (which can trigger droughts, forest fires, flooding, landslide, and so on) will increase. Alike, the impacts will become more severe and extensive due to the losses of ecosystems and the vulnerability of some population groups and specific regions; this points out that extreme weather events are not homogenously distributed over areas, neither in frequency nor intensity (IPCC, 2014; Zapata 2017). Therefore, the effects and costs of damages differ between localities. Moreover, these risks are usually measured as the economic costs of replacing or repair damages in infrastructure networks and basic services, as: water, electricity, and medical attendance (Lindell et al., 2003; IPCC, 2014).

For example, tropical cyclones are the most costly extreme weather event. They cause severe damages due to high-speed winds, storm surges, heavy rainfall, and flooding, leaving devastating impacts on affected localities (Defries et al., 2019; Lenzen et al., 2019). And as the severity of tropical cyclones increases, stronger winds will be reported, for which usually their costs increase to the cube relative to their speed (Stern, 2007).

- *Indirect impacts*

Likewise, these events can disrupt access to food supplies and influence the movement of people, other species, and resources that would have impacts on nutrition, availability of natural resources, land use, income level, and even stresses (IPCC, 2014). Furthermore, other effects cannot be ignored as the damages in environmental degradation and substantial health problems -physical and mental (IPCC, 2014).

Specifically, soil degradation will affect the stability of the buildings. Thus, an increase in the frequency and intensity of tropical cyclones will not only increase the direct costs of damages, but it will also lead to a rise in the risks of the impacts that could affect financial markets through higher and volatile insurance costs (Stern, 2007). Also, the risk of waterborne or respiratory infectious diseases and mental health problems (related to high levels of anxiety or post-traumatic stress) tend to increase when people are more exposed to extreme weather events, like heavy rainfall, floods, droughts, wildfires, or extreme temperatures (NCEH, 2020).

AGRICULTURAL PRODUCTION

- *Direct impacts*

Extreme temperatures are not optimal for agriculture production. This is, cooler or hot regions reduce crop yields. So, as temperature increases in cold weather, production is benefited. However, in tropical regions, every temperature rise can lead to a reduction in yields (Stern, 2007). Thus, the changes in climate are affecting agricultural production and distribution due to its dependency and sensitiveness over weather conditions. But, the reality is that the impacts – either benefits or losses– will differ across regions depending on changes in the frequency of extreme weather events, variation in water availability, increase in average heat hours, the extension of arid zones, increases in CO_2, and changes in wind speed and frequency. These can be considered the main drivers of damages and costs over the agricultural sector (Aydinalp, C., & Cresser, M., 2008; Godoy, E., 2017; PNUD – INECC, 2018).

- *Indirect impacts*

In lasts years, there have been reported global reductions in food production as a direct consequence of climate change and, as a result, the projected impacts for significant crops are turning negative (Sánchez et al., 2014; Murray-Tortarolo et al., 2018). These future reductions would threaten food security and trigger negative effects on the socio-economic conditions of the population working in the agricultural sector. The latter is a consequence of the reduction in the cultivation of some products, which would make them no longer economically viable while reducing the incomes of families who use agriculture for self-sufficiency (PNUD – INECC, 2018).

HEALTH IMPACTS

- *Direct impacts*

The effects of climate change will impact the environment's quality, which provides us with water, air, food security, and other resources. But also, and because human health has always been influenced by weather and climate, all these deteriorations will have a direct effect on human health in two different ways, by varying the frequency of diseases related to climate and weather factors (heat stress, vector, water, and foodborne diseases) and creating unprecedented problems in some regions (Balbus et al., 2016). Consequently, all these impacts imply an economic cost related to either: more governmental investments for prevention and attention of epidemiological diseases, expenditure on medical treatments by households, loss of working days and productivity, or premature death (EPHA, 2020).

As an example, variation in the water cycle will also affect health because droughts and floods have adverse effects. Droughts cause dehydration and may unleash forest fires that release pollutants. Floods can cause deaths by drowning or by triggering outbreaks of vector and water-borne diseases, like dengue and cholera (Stern, 2007). All these effects on health will vary between and within countries and will depend on vulnerability. Meaning how exposed, sensible, or susceptible are people or regions to new and more frequent illnesses and their respective damages, as well as their adaptation capacity (Balbus et al., 2016).

- *Indirect impacts*

Indirect impacts can result as more frequent diseases and extreme weather events are registered because it can induce to deficiencies in health care systems due to increases in demand for emergency services. Also, as other direct effects of climate change could increase food and energy prices, increases in malnutrition levels and productivity reduction in hotter regions are expected. Finally, economic problems and severe impacts of weather events related to climate change would lead to mental health problems, such as stress or anxiety (Paavola, 2017).

SEA LEVEL INCREASE

- *Direct impacts*

It is a fact that the sea level is increasing as a consequence of climate change through rising temperatures, which are triggering the melting of glaciers and ice sheets (Cassotta et al., 2019; Lindsey, 2020). Since 1880, the global mean sea level has registered a rise of about 21-24 centimeters, with increasingly accelerated growth rates during the last two decades (IPCC, 2013; Lindsey, 2020). Moreover, rising sea levels have direct impacts on coastal and island regions, threatening their ecosystems, infrastructure, and communities by provoking more frequent and extreme high-tide flooding, storm surges, erosions, and saltwater intrusion within coastal rivers and aquifers (Church & White, 2011; Sweet et al., 2017). This is, sea-level rise is risking coastal wildlife and its ecosystems, which protect them from extreme weather events. Also, saltwater is polluting freshwater used for agricultural purposes, affecting water supplies and harvest (Lindsey, 2020).

Following Kirezci et al. (2020), around 600 million people live in low elevation coastal areas, which will be affected as coastal flooding becomes a more frequent problem. Although high-tide flooding is not generally dangerous, it could be extremely expensive due to all damages it could cause (Lindsey, 2020). For example, some projections show that, if we do not assume adaptation measures, by 2100 around 0.5-0.7% of the world's habitable surface will be at risk by coastal flooding, which imply costs about 12-20% of the global GDP for damages in assets (Kierzci et al., 2020).

- *Indirect impacts*

Other effects that could result from rising sea level rise are increases in coastal protection costs, decreases in tourism demand, rises in insurance costs, geopolitical tensions, changes in fisheries productivity, and variations in commodity prices (Stern, 2007; Cassotta et al., 2019). All of them impact the local, national, and global economies. But also, a study confirms that associated costs to these events increased linearly with sea-level rise (Sugiyama, 2007).

ENVIRONMENT DEGRADATION

- *Direct impacts*

Environmental degradation occurs when natural resources are exploited rapidly, such that nature cannot restore them that fast; some of their direct impacts are quality reductions in air and water due to pollution, soil degradation, and coastal protection destruction (CEDRA, 2009). These negative effects are related to production processes, but also the environment is highly sensitive to climate change (Stern, 2007; CEDRA, 2009). Thus, the increases in temperatures and variations in rain patterns related to climate change could aggravate processes of environmental degradation and the vulnerability of regions to extreme weather events (Raleigh & Urdal, 2007; Warner et al., 2009; IOM, 2011).

- *Indirect impacts*

Furthermore, environmental degradation could trigger damages on environmentally dependent socio-economic systems; these related to threats in: food security due to soil degradation; health due to air pollution; inundation of coastal areas because of the protection reduction; freshwater scarcity; and migration (Raleigh et al., 2007; CEDRA, 2009; Warner et al., 2009). All of them causing considerable economic costs that could be reduced through adaptation behavior (Raleigh et al., 2007).

ENERGY SECTOR

- *Direct impacts*

We have been used to link winter with lower temperatures, where cold weather makes us consume energy for heating. In contrast, summer is identified as the warmest season in which energy is used for cooling. But, as the temperature continues to increase because of climate change, winters will tend to be less cold, and summers will become warmer. Hence, we will reduce our energy consumption during winters, and we will increase our consumption during summers (Pilli-Sihvola et al., 2010; Auffhammer & Mansur, 2014; PNUD-INECC, 2018).

According to Pilli-Sihvola et al. (2018), variations in energy consumption will depend on the region's geographical location. This is, the nearest the regions are to the equator with more continental weather, the more likely consumption of energy for cooling will exceed the decreased use of energy for heating. However, the net increases in energy demand would be accompanied by variations in energy expenditure, generating additional costs or savings for electricity consumers; where the most affected could be the residential, commercial, and industrial sectors, as they are the main consumers of electricity, natural gas, and oil (Auffhammer & Mansur, 2014). Nevertheless, there is high uncertainty over the energy costs related to climate change because they will depend on technology, the consumer response to weather variability, and their adaptation to rising temperatures (Auffhammer & Mansur, 2014).

1.5. Growth Limitations[12]

The impacts of climate change on countries are mainly derived from the effects of extreme weather events and declines in the environment. And, as the frequency and intensity of extreme events have already increased during the last decades, the losses related to the damages are also increasing around the world, mainly in developing countries. In those countries, the financial costs related to natural events represent a greater amount in the proportion of GDP, and deaths derived from the same events are more frequent. Other situations could be related to the cuts of revenues and the increases in expenditure due to extreme weather events –e.g., reduction in the availability of food or water will lead to import supplies–, which affect municipal and national budgets (Unterberger, 2018).

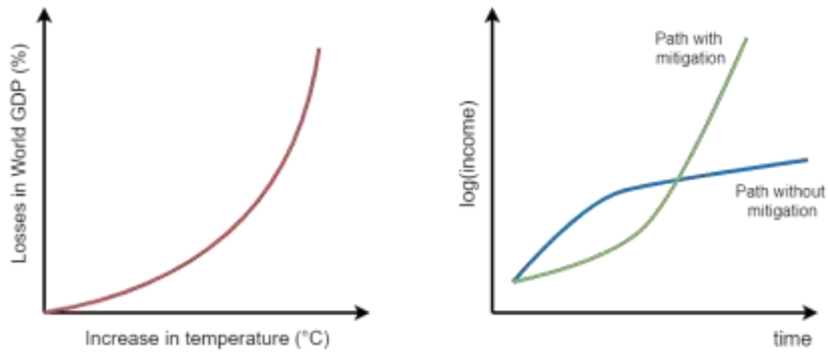
Also, the reduction of agricultural production due to devastating events could reduce household incomes and raise unemployment in rural areas, leading to an increase in poverty. Where must of the time, these impacts are followed by increases in food prices. Besides, health impacts are also related to growth reductions. For example, malaria is estimated to reduce growth by 1.3% per year in the most affected countries.

Moreover, as temperatures continue to increase, the damages of climate change are expected to affect global growth due to the convexity of the damage function. And, because developing countries are at higher risks due to their high vulnerability –geographic exposure, low incomes,

[12] Stern (2007). Chapter 4 and 5.

greater reliance in climate-sensitive sectors–, they could be more affected, leading to stunted growth and development, as well as to fall into the poverty trap.

Figure 1.5. Damage costs of climate change in the economy and growth paths



Source: Kolstad (2010) & Stern (2007).

1.6. Public Policies

The IPCC (2014) has declared that adaptation and mitigation policies are needed to counter the effects of climate change by protecting vulnerable and exposure groups and reducing risks. Nevertheless, there may be limitations for planning and implementing these policies arising from: limited human and financial resources; different risk perceptions; competing values, conflicting objectives or tensions between different policy agendas and their priorities; integration and government coordination constraints; uncertainty in projected impacts; limited tools to estimate the effectiveness of adaptation; and insufficient research (Mimura et al., 2014; IPCC, 2014).

Moreover, although mitigation can include either benefits and risks, the risks do not reverse the severe climate change impacts. In contrast, the delay of mitigation policies can be crucial to avoid costs and damages in the long term (IPCC, 2014). Also, nowadays, there are multiple ways and instruments to achieve mitigation or adaptation by transformations in political, social, and technological decisions and actions that can promote sustainable development. However, these policies should be accompanied by effective institutions and governments, investment and innovation in technologies or sustainable housing for better results (IPCC, 2014).

2. CONTEXTUAL FRAMEWORK

Mexico is a highly vulnerable country to climate change given its geographic location, climatic, orographic, and hydrological conditions, and its volcanic and seismic activity. For these reasons, it is prone to more frequent and extreme impacts by natural phenomena that would negatively affect some systems, especially the economic one due to the increase in environmental costs and the rise in inequality created by differences in vulnerability between social groups and regions (OECD, 2013; SEMARNAT, 2014; INECC, 2019).

It is also projected that the impacts will be heterogeneously distributed around the country due to different types of climate, distribution of natural resources, infrastructure, economic development, and demographic concentration (Sosa-Rodríguez, 2015; INECC, 2019). And, according to the Special Program of Climate Change in Mexico (PECC 2014-2018), 319 out of 2,446 municipalities were highly vulnerable to impacts of climate change in 2015, mainly to droughts, floods, and landslides. However, this number increases to 480 if we take the municipalities with high and very high vulnerability, representing 20% of the cities at the national level (DOF, 2014).

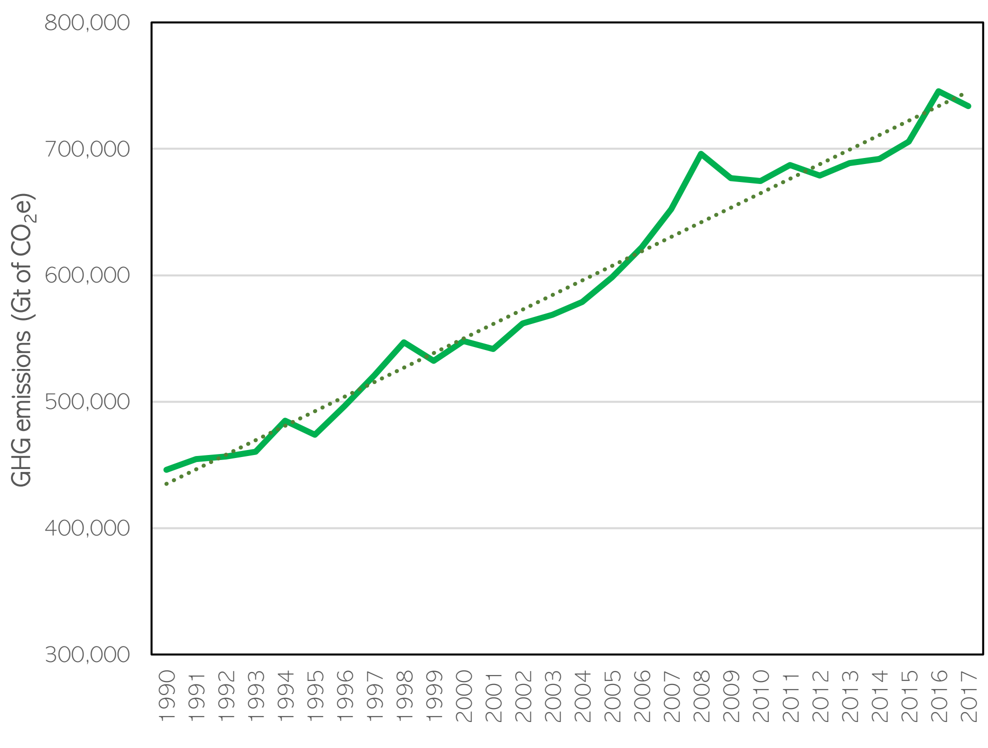
Moreover, some natural phenomena as hurricanes, droughts, extreme temperatures, and rains have occasioned high economic and social costs, as reported by INECC. Jointly, all those extreme events have threatened welfare, legacy, life, environment, biodiversity, and development opportunities (INECC, 2019). But these are not the only effects that Mexico is facing up and will face due to climate change.

2.1. GHG emissions in Mexico

Mexico has reported its emissions since 1990 in a "National Inventory of Emissions of Greenhouse and Compound Gases" (INEGYCEI) by the National Institute of Ecology and Climate Change (INECC) -due to its commitment to UNFCCC. They estimate the emissions of carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, hexafluorides, and black carbon; using globally comparable methodologies (INECC, 2015).[13]

In **graph 2.1.1.** we can observe the trend of carbon emissions and some equivalents from 1990 to 2017. As well noted, the trend still positive even though Mexico has assumed some international agreements on reducing its emissions. Also, there is an increase of 65% in emissions at an annual rate of 1.9% over the whole period. However, the annual growth rate has been slowing down during the last years reported (SEMARNAT & INECC,2018). This is attributed to the decrease in oil and carbon use, a rise in the electric power generation system's efficiency, a substantial increase in renewable energy, and a slight increase in natural gas use (SENER, 2018).

Graph 2.1.1. CO_2 GHG emissions in Mexico (1990-2017)



Source: Own elaboration based on data of INECC, Mexico. 2018.

[13] For more information visit: https://www.gob.mx/inecc/acciones-y-programas/inventario-nacional-de-emisiones-de-gases-y-compuestos-de-efecto-invernadero

GHG EMISSIONS BY SECTORS

The INEGyCEI reported can be disaggregated into four sectors to have a better analysis, these are: (1) energy, (2) industrial processes, (3) waste, and (4) agriculture, silviculture, and other land use. In **graph 2.1.2**, it is shown that the energy sector is the most significant contributor to emissions in the country. Just in 2017, this sector emitted 71.2% of the total emissions in Mexico.[14] This can be attributed to the burning of fossil fuels, mainly due to electricity production and transport.

Furthermore, the energy sector has grown its emissions by 73% during the 1990 – 2017 period, at an annual average rate of 2.1%. Besides, its share in total emissions has remained constant, around 67%-73% for the reported years. Also, within the sector, electricity production and transport are the more significant contributors to emissions, but they have decreased their participation by nine percentual points. In detail, during the '90s, both categories represented 54% of total emissions by the energy sector, while for the last reported period, this participation was equal to 45%.

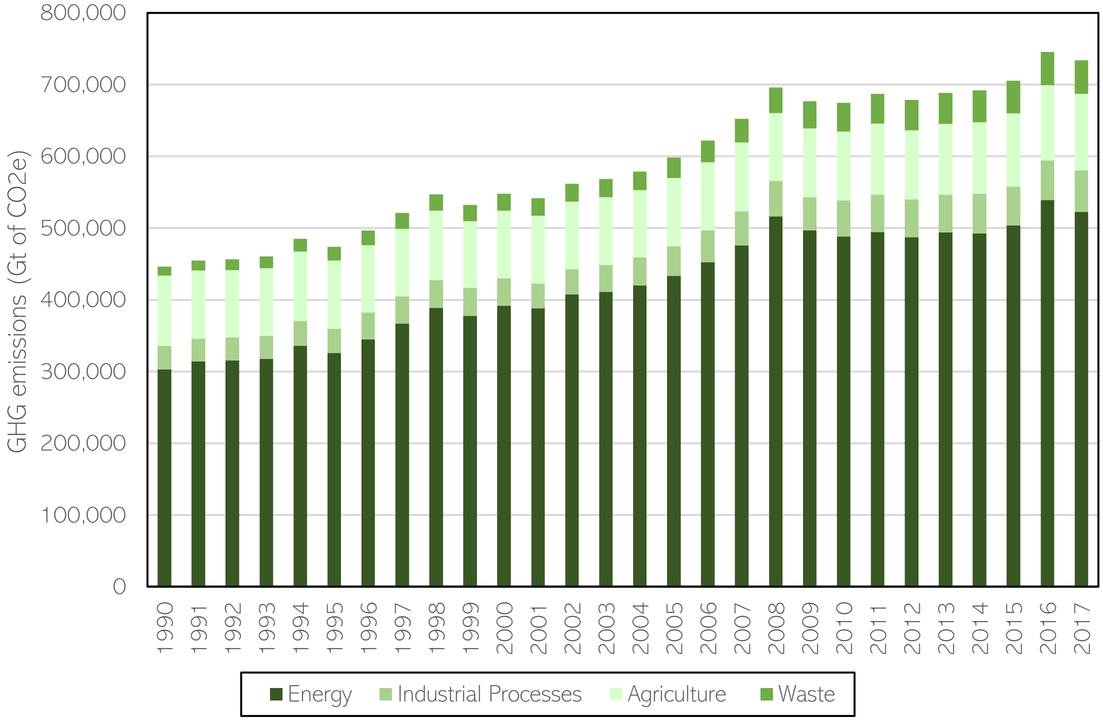
Moreover, the industrial processes and waste sectors increased by 78% and 272%, respectively, during the 27 years reported. As noticed, the waste sector reported the highest growth rate, which includes the disposal and treatment of solid waste and wastewater. Jointly, both sectors contributed by 14.2% in total emissions for 2017, 4.1 percentual points up compared to 1990. But the waste sector presented more significant increases in total emissions, going from 2.8 to 6.3%.

Finally, the agriculture and silviculture sector registered an increase of 8.8% in its emissions, as well as a decrease in 7.45 percentual points on its share of total emissions, during the reported period. Nevertheless, if we consider emissions from land-use changes and those absorbed by the Earth from the atmosphere (LULUCF), this sector's coefficients will turn negative. And, instead of increases, we will present around a 10% decrease in emissions from this sector between 1990-2015. This is, the land has decreased its absorption capacity by 10% compared to 1990.

[14] Total emissions reported here reported does not include Land Use, Land Use Change and Forestry (LULUCF).

Graph 2.1.2. Greenhouse Gas Emissions by sectors in Mexico (1990-2017)

*Excluding LULUCF



Source: Own elaboration based on data of INECC, Mexico. 2018.

In conclusion, GHG emissions in Mexico have tended to grow at accelerated rates over the years. This could be related to the economic and population growth, factors which are perceived as the main drivers of increases in CO_2 emissions (IPCC, 2014). The most significant contributor to these emissions has been the energy sector, derived from energy production and transport. However, the waste management sector has increased its contributions the most, while the LULUCF category has been decreasing, which means less gas absorption by land. Therefore, if GHG emissions related to human activities continue this positive trend, the atmosphere's concentration and heat retention will increase, triggering climate change effects. This will lead to a series of impacts in the environmental sphere and productive sectors (SEMARNAT, 2018).

2.2. Observed effects of climate change in Mexico

According to SEMARNAT (2018), Mexico has already reported some events related to climate change, as:

- *Temperature changes:* an increase of 0.85°C in the average temperature was reported in Mexico between 1960 and 2012. And it is estimated that the north is the most affected region, with increases around 1.2 and 1.5°C above the historical average. Also, since 2005, annual temperature records have been above the average annual temperature value (21°C). Likewise, 2016 and 2017 were rated as the warmest years since 1971.

- *Changes in rain patterns:* precipitation has not followed a clear pattern of change because it varies differently by region. But, in some of them, the number of intense storms has been increasing.

- *Forest loss:* forest fires are causing a loss in vegetation and forests, which are related to increasing temperatures.

- *Glacier loss:* Thaws also occur in ice or glaciers that cover mountains. They can have significant socio-economic consequences by reducing the availability of water in river basins. In Mexico, there have been reductions in the glaciers of Iztaccihuatl, Popocatepetl, and Pico de Orizaba.

- *Diseases appearance:* some regions, like Chihuahua, have presented dengue cases. Something that could be unusual in this area.

- *Frequent impacts of natural phenomena:* the number of disasters per year shows a growing trend, particularly of extreme hydrometeorological phenomena are more frequent. As evidence, we have that while between 2000 and 2003 there were declared 72 disasters, between 2012 and 2015 were reported 190.

- *Droughts:* during this century, there have been registered five consecutive events (2000-2003, 2006, 2007-2008, 2009, and 2010-2012). Especially in 2011, the drought-affected 90% of the national territory. And, between 2016-2018, there was reported another drought that affected, annually, less than 60% of the national surface.

- *Sea level rise:* a lot of coastal areas, between the Gulf and Pacific, have registered a sea-level increase between 1950-2000. In the Gulf of Mexico, annual increases between 1.9 to 9.16 millimeters were recorded in Veracruz and Tamaulipas, respectively. While in the Pacific, the annual increments were between 4.23 millimeters in Sonora and 3.28 in Colima.
- *Biodiversity loss:* the impact of climate change on biodiversity is already noticeable in our country. Changes occur mainly in broad-leaved coniferous forests and cloud forests, as well as in marine and insular ecosystems.

All these observable changes, attributable to climate change effects, are threatening the most basic resources like water, land, food, health, and the environment. As we already discuss, they imply direct or indirect economic costs due to their impacts on productive sectors. In addition, the estimation of these costs is considered fundamental to perform a cost-benefit analysis for the design of mitigation and adaptation policies with the goal to develop strategies and actions to minimize these costs, mainly through reducing vulnerability (SEMARNAT, 2018).

2.3. Environmental Policies in Mexico

The Mexican government has committed to act against climate change and it was one of the first countries to create climate legislation in 2012 - the "General Law on Climate Change" (LGCC). However, no favorable results have been reported because Mexico continues registering high GHG emissions rates, which has led some international organizations to consider climate policies insufficient (CAT, 2020).

Firstly, the LGCC was created to assess climate policy, which must comply with specific objectives for mitigation and adaptation (CEMDA, 2019). It has also set institutional foundations and defined long-term goals as mandatory. And, in 2018, through a decree, it formalized the basis for fulfilling its international commitments. However, there still challenges because the law has unclear mandates for the responsible institutions, does not provide a concrete finance strategy to tackle climate change, neither include a concrete political instrument (Averchenkova & Guzman, 2018; CAT, 2020).

Moreover, in 2014, Mexico also implemented a carbon tax. This tax sets a price on emissions of carbon through a tax rate on the carbon dioxide content of fossil fuels; and in agreement with the Secretariat of Finance (SHCP), the tax has been implemented to achieve two objectives: reduce emissions and increase tax revenues (Plataforma Mexicana de Carbono, 2017). Later, in 2017, the Law of Special Tax on Production and Services (IEPS) was amended, and it was established the option for taxpayers to make the payment of the tax on fossil fuels through the delivery of the emission reduction credits (CERs) (DOF, 2017). But, according to the CAT (2020), its impact on its commitment to reducing GHG emissions remains unclear.

Finally, the current administration is going backward in environmental issues as they are favoring fossil fuels over renewable energy. This after promoting the construction of a new refinery, "Dos Bocas", with a main goal: to strengthen the country's energy security (Government of Mexico, 2020); also, in 2019, a budget was programmed by the Federal Electricity Commission (CFE) for the rehabilitation of coal-fired power plants, which some of them were already scheduled for retirement in pasts administrations (Solís, 2018; CAT, 2020). It just remains to say that all these policies together, which undermine international agreements and the LGCC itself, could have negative long-term consequences. That is why a more in-depth analysis of this issue is urgently needed to assess its economic, social, and political impacts. Nonetheless, that is another topic of discussion that will not be addressed.

3. METHODOLOGY

It is worth mentioning that it could be challenging to measure all economic costs of climate change because it is complex to establish a price for some impacts that are not recorded in the market, as: species extinction, further losses in biodiversity, or increases in social conflict (Ackerman & Staton, 2008). Due to limitations in data, we will not consider these effects neither the indirect impacts, despite the fact this tends to underestimate the real impacts of climate change on the economy.

Besides, the aim of this work is to calculate the direct costs of climate change damages in Mexico. According to this, all observable climate impacts in Mexico shall be considered. Nevertheless, due to the lack of public records, it will not be possible to analyze some specific direct costs, as damages from sea-level rise and variations in energy consumption. More details of the data found, as well as methodology, will follow.

From now on, whenever the term economic cost is used, we will be referring just to the direct costs of climate change damage.

3.1. Data

- *Environmental Degradation Costs*

INEGI offers in its System of Economic and Ecologic Accounts for Mexico (SCEEM) some information about the exhaustion of natural resources, environmental degradation, environmental protection expenditures, and Green GDP for the 2003-2019 period. For our purposes, we will focus on environmental degradation costs, which are defined as those costs that society would have to incur to prevent or remedy deterioration of quality of the environment due to economic activities -meaning: production, distribution, and consumption of goods and services (INEGI, 2020). To estimate these costs, INEGI considered four specific issues: (1) emissions into the atmosphere, (2) soil degradation, (3) management and control of solid urban waste, and (4) sewage discharges.

- *Extreme weather events*

To analyze the costs and frequency of extreme weather events during the lasts years in Mexico, governmental databases were used from CENAPRED and CONAGUA. The annual reports (Socioeconomic Impact of the Main Disasters in Mexico) from CENAPRED register the extreme natural events economic costs by type of phenomena from 2000 to 2019. They present two databases with different aggregation levels of the events: (1) local level and (2) national level. This reduces the registered events for the second database because adding up the number of registered phenomena at a local level to obtain the national level could lead to a double-counting problem. Nevertheless, they reported similar economic damages with slight variations.

CONAGUA, in its National System of Water Information (SNIA), reported the number of cyclone impacts in Mexico from 1970 to 2019. They present the data in 4 categories: tropical depression, tropical storm, moderate hurricane, and intense hurricane. These subdivisions help to analyze not just the frequency but also the intensity of tropical cyclones in Mexico.

Furthermore, the registered emergency declarations of disaster, emergency, and climatic contingency from CENAPRED were used from 2000-2019 to estimate the frequency of other extreme weather events impacting Mexico.[15] The other selected extreme weather events were rains and floods, sinks and landslides, forest fires, droughts, extreme temperatures, winds, storms, storm surges, tornadoes, snowfalls, and hailstorms.

It was decided to use these databases for the 2000-2019 period at a national level because they reported more disaggregated data by natural phenomena, and it is frequently updated. Also, it is worth mentioning that the presented costs consider direct damages of extreme weather events at the time of the impact or in an immediate period. These could be: damages to public, private, and social infrastructure, repercussions in goods or services, and their respective impact in agriculture, livestock, tourism, commerce, industries, and other services. Moreover, CENAPRED reported that costs were obtained through estimation of losses and damages in social (housing, health, and

[15] The declaration of emergency is the act by which the government recognizes that one or more municipalities are at risk by a natural disruptive agent and therefore requires immediate assistance to the population. Furthermore, the declaration of disaster is the act by which the government recognizes the presence of an extreme natural event for which damages exceeds the local financial and operational capacity to deal with, in order to be able to access resources from the financial instrument for dealing with natural disasters, such as the Natural Disaster Fund. For more information visit: http://www.atlasnacionalderiesgos.gob.mx/apps/Declaratorias/#

education) and urban (roads, street lighting) infrastructure, and the productive sector; where the damages are valued as the repairing cost, according to its market value.

- *Economic losses in agriculture*

The data used for this section was obtained from the Food and Fisheries Information Service (SIAP), reported by the Mexican Secretariat of Agriculture (SAGARPA) for the 2000-2019 period. In particular, records of sown and harvested areas were identified to obtain the crop yield. The production volume, the value of the harvested product, and the area affected by climatic factors were also used. These data were also available by hydro mode –rainfed and irrigation fields–, the type of crop and locality.

It is considered important to identify the hydro mode of fields because these differences could imply a greater vulnerability over climate change effects. On the one hand, a rain-fed crop surface is defined as the area in which the crops' complete development depends on the rainfall patterns or residual soil moisture. On the other, irrigation crop surface is where the artificial water application is carried out to benefit the crops (Campo Mexicano, n.d.).

- *Health impacts*

Due to data limitations, just the costs derived from dengue and acute respiratory infections will be considered. And, according to INECC & INSP (2006), these diseases have affected the general population without distinctions and increased medical assistance, emergency services, hospitalizations, morbidity, and mortality due to climate change effects.

Moreover, to estimate these costs, the Unique Epidemiological Surveillance System (SUIVE), as well as other governmental reports from the Secretariat of Health (SSA) and National Institute of Public Health (INSP) that register the incidence of these diseases, as well as SEMARNAT and INECC that report PM_{10} concentration, will be used.

3.2. Method

In order to obtain the direct costs of climate change damage in Mexico, national accounts were used to obtain costs by type of damage. Also, to allow for cost comparison during the selected period, data were used at constant prices, with 2013 as the base year. In addition, when data was not available at constant prices, the INEGI’s GDP deflators were used since they report 2013 as the base year. Subsequently, once obtained all the available economic costs, these were are added up to obtain the total direct costs of climate change damage (DCCCD’s):

$$DCCCD's = EDC + TCC + EWC + AGC + HC$$

Where EDC corresponds to the costs of environmental degradation, TCC to the costs of impacts of tropical cyclones, EWC to the damages of other extreme natural events, AGC to the losses in the agricultural sector given the variations in climatic stressors, and HC aggregates the costs associated with health damage from vector diseases, such as dengue and respiratory infections from PM_{10} particles. Besides, for the particular case of the health impacts, it was required a further method that will be described in the appropriate section.

4. RESULTS

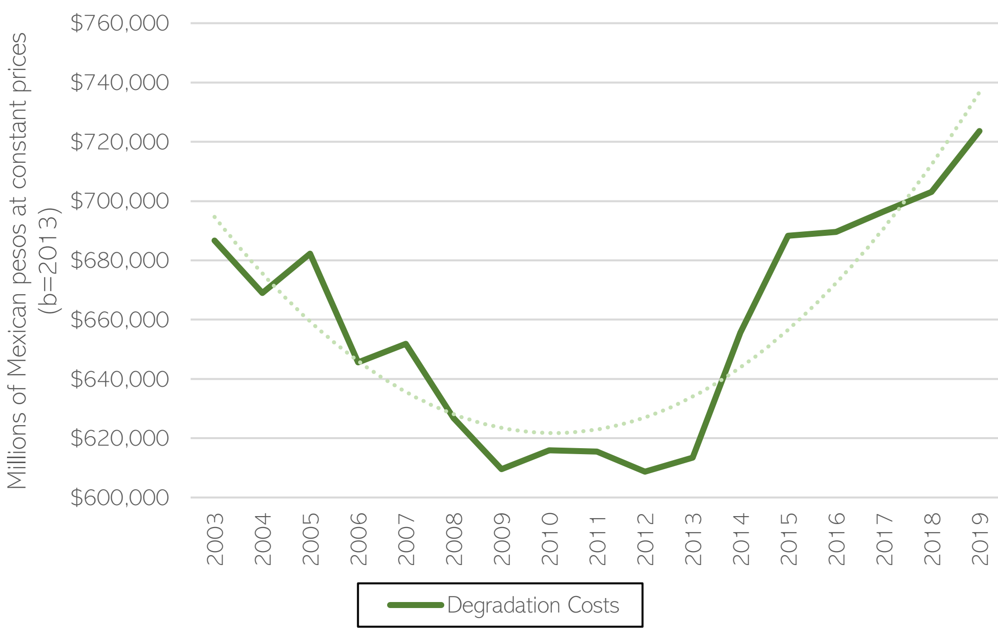
As it has frequently been stated that climate change could severely impact the economy, mainly on growth and development, this chapter will analyze the direct costs of climate change by type of damage, trend, and the ratio to Mexican GDP for the 2003 – 2019 period. This to identify the structure and how do these costs are behaving.

4.1. Environmental Degradation Costs

In **graph 4.1.1.**, we can observe that the environmental degradation costs registered a consecutive fall of 10.7% during the first ten years, from 2003 to 2012. After that, it started a rising period that has surpassed the initial record due to the accelerated annual growth rates reported from 2003-2019, which are above the average of 5.3%. Thus, the observed trend that better adjusts to the data shows a "U" shape, meaning that we expect further increases in these costs.

Graph 4.1.1. Environmental Degradation Costs in Mexico (2003-2019)

Millions of Mexican pesos at constant prices (b=2013)

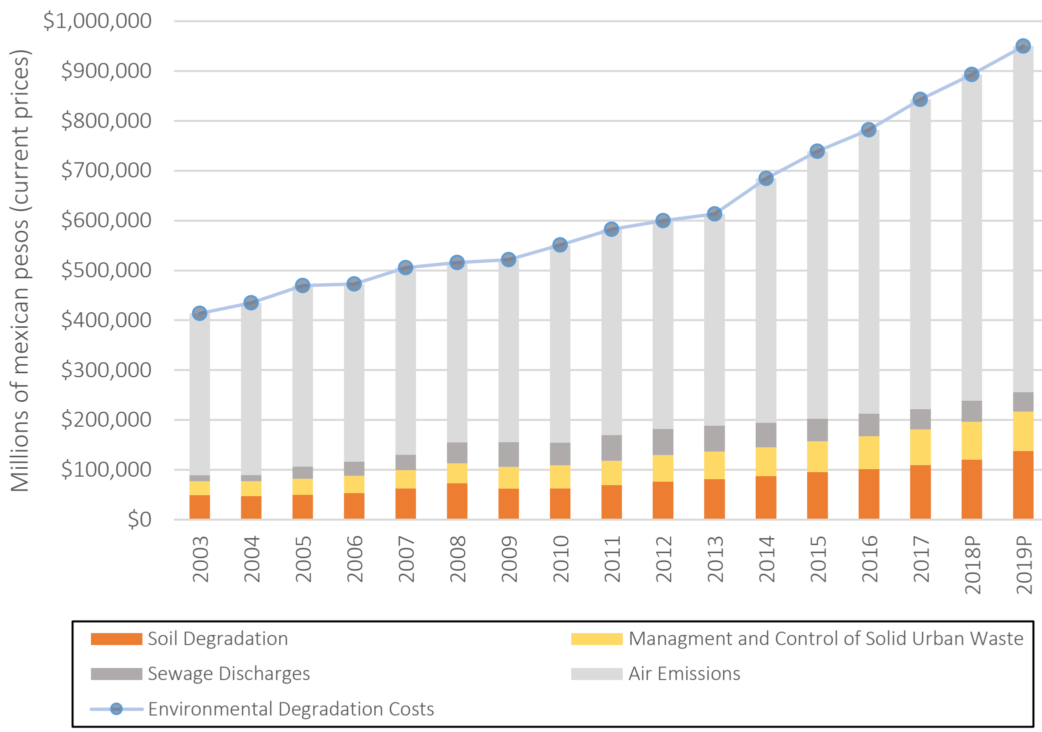


Source: Own elaboration based on data of INEGI, Sistema de Cuentas Nacionales de México (2020).

The main factor of the acceleration is attributed to an extreme increase in air emissions costs, but also the soil degradation costs started to present higher increases for the last reported years (see **graph 4.1.2.**). Furthermore, we can point out that air pollution costs represent the largest share of total costs of degradation. On average, they represent 72.81% of total costs, but this share has fluctuated between 69 – 79%.

Graph 4.1.2. Environmental Degradation Costs in Mexico (2003-2019)

By type of degradation



Source: Own elaboration based on data of INEGI, Sistema de Cuentas Nacionales de México (2020).

Thus, it will be critical to analyze the costs of emissions into the atmosphere. For this, the available data allows us to disaggregate by the source of emissions: fixed, mobile, and aerial. [16]

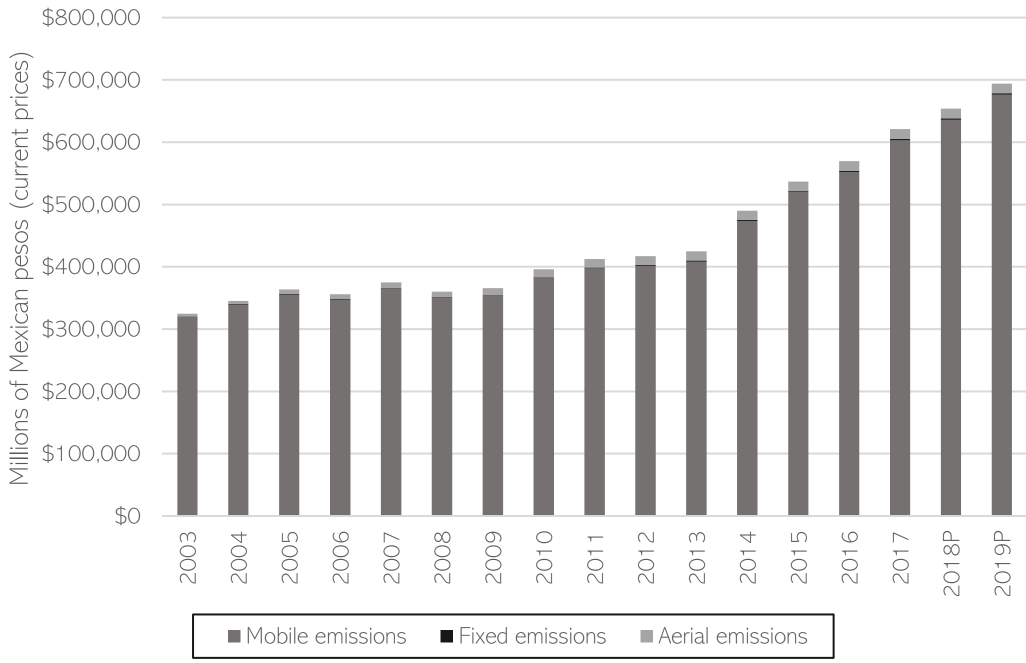
[16] According to INECC, they are three different sources of emissions:

1. **Fixed emissions** can be divided in two types: punctual and natural. The first ones are derived from energy generation and some industrial activities. The latter includes all those emissions generated by volcanos, oceans, land, and other natural systems.
2. **Mobile emissions** are represented mainly by transport: airplanes, helicopters, railways, trams, tractors, buses, trucks, automobiles, motorcycles, boats, non-fixed equipment, and machinery with combustion engines that due to their operation generate polluting emissions into the atmosphere.

And, as a result (see **graph 4.1.3.**), we obtain that mobile emissions are the most significantly responsible for air emission costs, representing, on average, 97.06% of the air pollution costs. In contrast, the fixed emissions represent, on average, 0.2% of air pollution costs in Mexico for the reported period.

Graph 4.1.3. Air Pollution Costs in Mexico (2003-2019)

By source of emission



Source: Own elaboration based on data of INEGI, Sistema de Cuentas Nacionales de México (2020).

Hence, and as mentioned before, the greatest contributors to environmental degradation costs are derived from air pollution costs, specifically mobile emissions that are mainly caused by transports. Thereby, the air pollution generated by transport emissions in Mexico during the 2003-2019 period represented 70% of the total costs of degradation, while GHG emissions by transports represent, on average, 22.74% of total emissions.

3. The **aerial source** includes all emissions caused by activities and processes, like consumption of solvents, cleaning of surfaces and equipment's, and distribution and storage of LP gas. Also, emissions derived by the treatment of wastewater, landfills, and more activities, are included here.

More information in: https://cutt.ly/MhG03pY.

Finally, these accelerated rates are preoccupying. They imply that emissions from transport on the atmosphere that lead to air pollution are extremely costly. We can also note, in the trend of the environmental degradation costs, that in 2019 reported a record of $723 billion of Mexican pesos. Simultaneously, water and land quality has shown decreases, which also contribute to raising these costs.

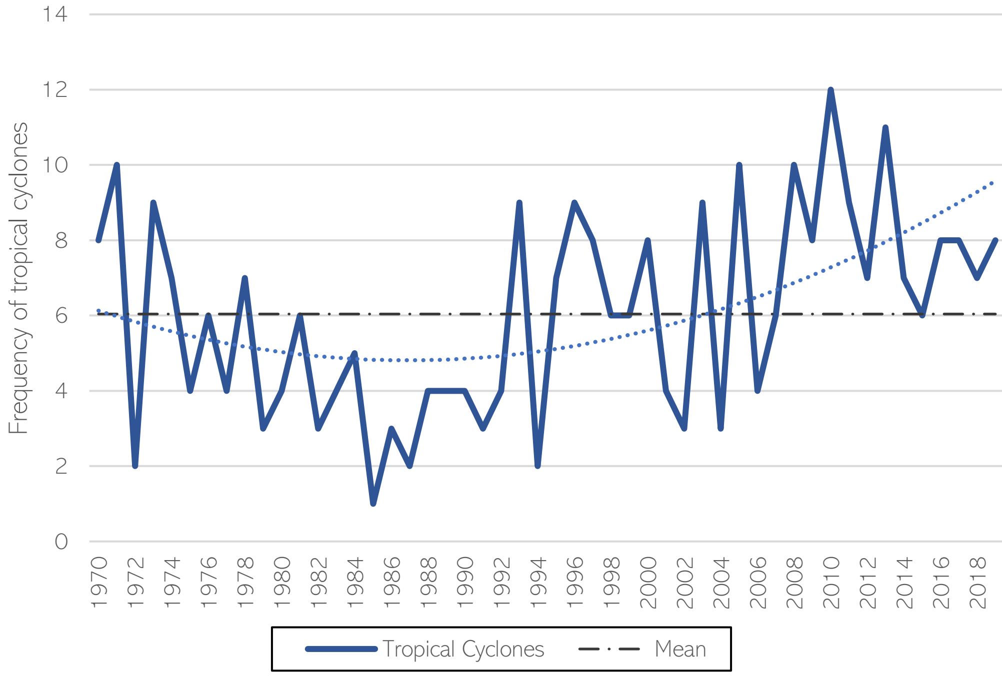
4.2. Economic losses by tropical cyclones

Mexico is located between the two most immense oceans, east the Atlantic and west the Pacific. This location makes the country more exposed to cyclone impacts because 17 out of 32 entities are situated on the seacoast, representing 56% of the national territory (SEMARNAT, 2011). Also, it is a fact that the population is growing at higher rates in coastal areas, mainly in Quintana Roo and Baja California Sur.[17] This means that infrastructure will grow and increase the risks of damages and, hence, tropical cyclones' costs.

According to CONAGUA, the historical annual average of tropical cyclones directly impacting Mexico is around six (see **graph 4.2.1.**). This is, on average, six tropical cyclones impact this country every year, with a higher presence in the Pacific. Also, we noted a decrease in the frequency of these events until 1985, and then it started to increase again. Now we can observe that since 2008 these phenomena have been above the average. About the intensity, most tropical cyclones in Mexico have impacted as tropical storms; nevertheless, the frequency of moderate hurricanes (categories I and II) are starting to rise.

[17] According to INEGI’s data, during the periods 1990-2000, 2000-2010, 2010-2015, the annual average growth rate of population for the aggregated entities located on coastal areas was above the national average; opposite to the other entities where the majority presented an annual growth rate below the national average.

Graph 4.2.1. Tropical Cyclones directly impacting Mexico (1970-2019)

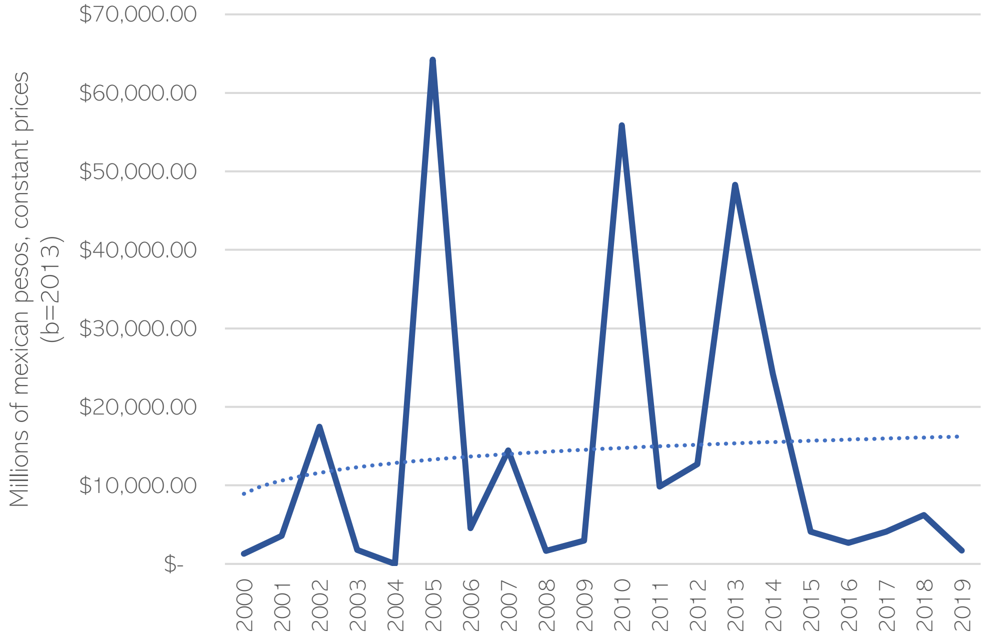


Source: Own elaboration based on data of CONAGUA, 2019.

All the above mentioned is relevant because these phenomena imply huge damages. In Mexico, the impacts of tropical cyclones are the more significant cause of economic losses by extreme weather events due to the increase in humans' settlements in risks areas and environmental degradation, representing 50% of the total costs caused by natural events in Mexico.

According to CENAPRED, the higher costs related to these events are registered in the country's southeast, where the most vulnerable municipalities are located. Also, the most affected year, in economic terms, was 2005, with losses of $64.3 billion of Mexican pesos (see **graph 4.2.2.**). Besides, 2010 and 2013 reported significant losses, $55 and $48 billion of Mexican pesos at constant prices, respectively. Moreover, when compared to the frequency of tropical cyclones impacting Mexico, we obtain that the most affected years by these phenomena were 2005, 2008, 2010, and 2013.

Graph 4.2.2. Economic costs of tropical cyclones in Mexico (2000-2019)



Source: Own elaboration based on data of CENAPRED, 2020.

Hence, given that the frequency of tropical cyclones has increased and will continue to grow as an effect of climate change (Lenzen et al., 2019), it is essential to aggregate these economic damages as a determining factor of the economic costs of climate change in Mexico. Also, because it is noted that the costs are related to the frequency of these events.

Nevertheless, with the results we cannot define a trend for these costs as they are extremely volatile during the reported period. Thus, for further analysis, it will be needed a larger period to observe the historical damages of climate change.

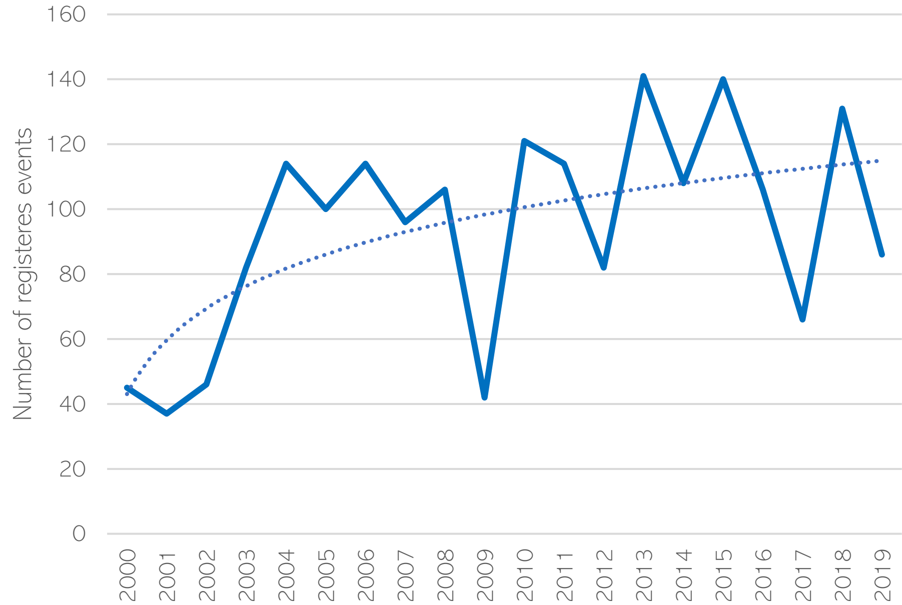
4.3. Economic losses attributed to other extreme weather events

Indeed, we cannot relate all disruptive natural events as a climate change effect because they have always existed. However, we have observed a sustained increase in the reported events since 2002 (see **graph 4.3.1**). As evidence, we can point out that we have been registering constant records of events in recent years, with the highest of 141 declarations recorded in 2013 and followed by 140 in 2015. Instead, the lowest value was reported in 2001, with 37 declarations.

Furthermore, the average of the last five years reported is around 106 events per year, while the 2000-2005 period is approximately 65. So, we can relate more frequent hazards during the last decades with an alteration in climatic systems, a direct consequence of climate change.

Nevertheless, extreme weather events are incredibly volatile. That is, they can reach a local minimum in one year and then break the record of the largest number of events, like the 2009-2010 period where the reported events from one year to another almost triple. This is mainly due to the uncertainty that characterizes them because we cannot be sure when an extreme natural phenomenon will impact, neither the precise location nor its intensity. Therefore, we cannot predict with certainty the damage nor the related costs.

Graph 4.3.1. Frequency of extreme weather events in Mexico (2000-2019)



Source: Own elaboration based on data from CENAPRED, 2020.

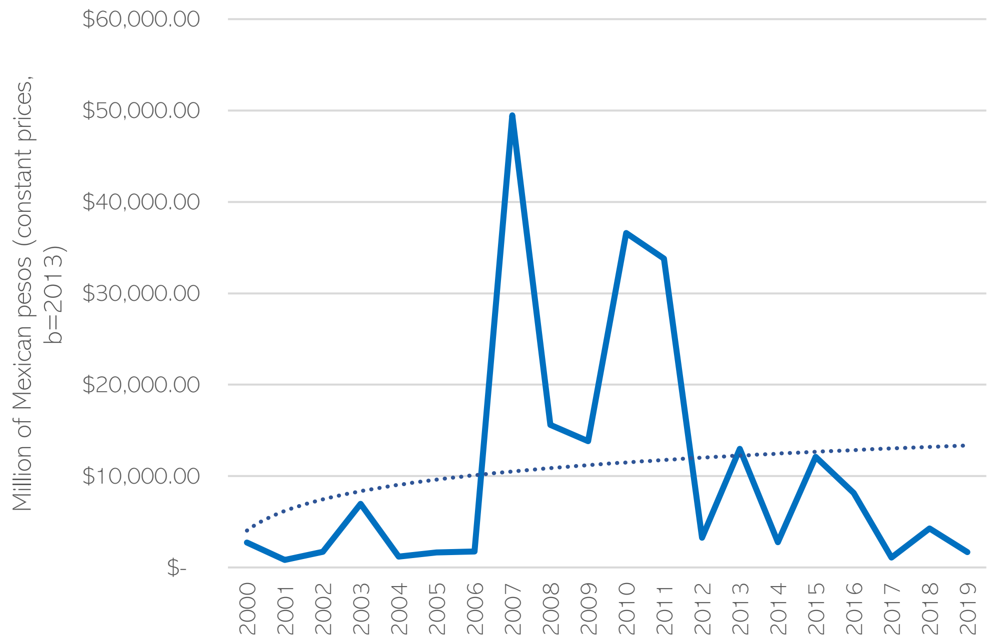
Regarding the damages attributed to extreme weather events for the reported period (2000-2019), the annual average costs are estimated at $10.6 billion of Mexican pesos. And, the economic losses attributed to direct impacts represented around 0.07 [0.006 - 0.33] % of the GDP, being 2007 as the year with more recorded losses as a proportion of GDP.

Moreover, evidence has shown that, on average, eight out of ten negative events were caused by hydrometeorological phenomena -in particular, extreme rainfall-, becoming the most frequent type of hazard (CENAPRED, 2020). Also, the damages attributed to hydrometeorological events and wildfires represented, on average, 45% of the total costs by major disasters occurring in Mexico, as defined by CENAPRED (increasing to 90% when tropical cyclones costs are included).

Likewise, rains, floods, and tropical cyclones were the events that left more affected people in the whole period. Simultaneously, at a municipal level, between the 2001-2013 period, 1951 municipalities (79.4% of the total municipalities) were declared, at least one time, under disaster conditions due to hydrometeorological events (SEMARNAT, 2014).

Finally, it is important to note that there is a positive, though weak, relationship between the frequency of events and the damage costs. This could be related to their intensity, which is usually low in several events and reduces the severity of damages. And, although the costs of the damages have not increased as sharply as the frequency of extreme weather events in the last years, they follow a similar trend. This could mean that costs would continue to increase as more events are recorded as an effect of climate change.

Graph 4.3.2. Economic costs of extreme weather events in Mexico (2000-2019)



Source: Own elaboration based on data from CENAPRED, 2020.

4.4. Agriculture

Agriculture is the "science, art, or practice of cultivating the soil, producing crops, and raising livestock and in varying degrees the preparation and marketing of the resulting products." (Merriam-Webster, n.d.). Nevertheless, this section refers only to the practice of cultivation of the soil for growing the crops to provide food, wool, and other products, excluding the livestock activity; therefore, the direct costs of climate change in Agriculture, presented here, allude to the economic losses in crops due to extreme climate events and plagues.

It is estimated that around 16% of the national territory is destined for agricultural production by irrigation or rainfed seeding (Appendini & Liverman, 1994). On average, 75% of the sowing agricultural area corresponds to rainfed crops -or its equivalent, 16 million hectares-, which are more sensitive to weather conditions due to their dependency on foreseeable rainfall and runoff patterns (Murray-Tortarolo et al., 2018). Nonetheless, the hectares attributed to these crops have been declining during the last years, from 77.95% to 70.79%. This corresponds to a decrease in 7.16 percentual points during the 2000-2019 period.

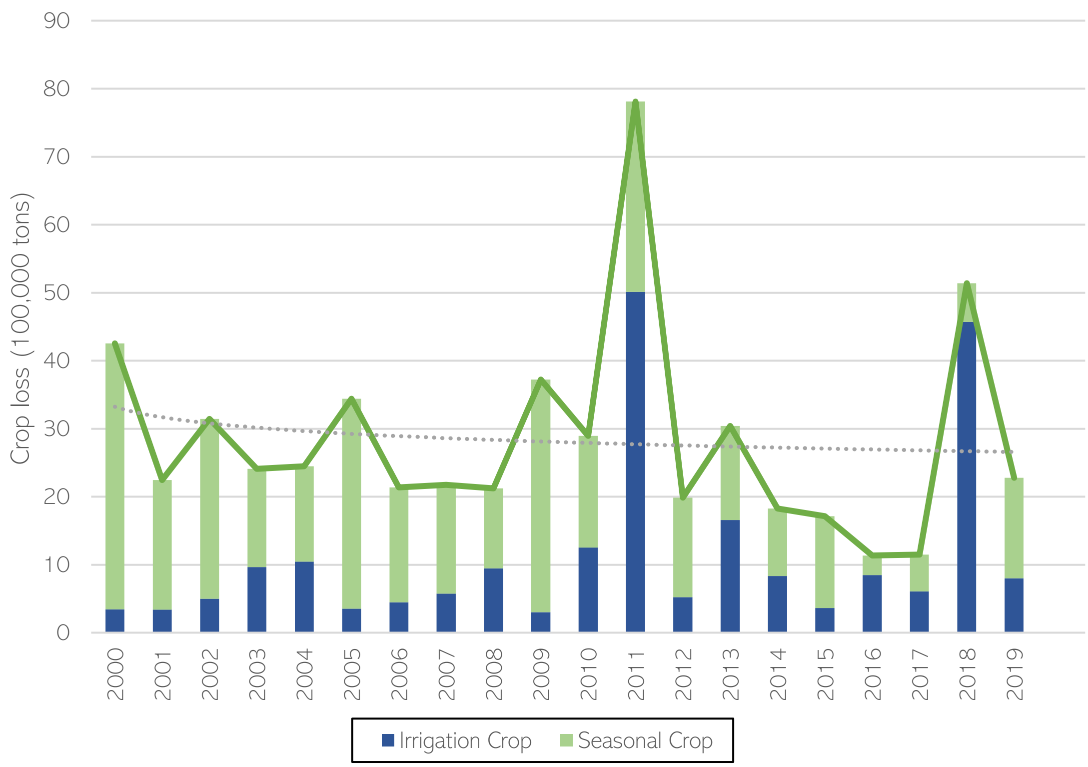
The remaining area, formed by irrigation crops, have grown as rainfed fields are declining. However, the evidence shows that although they also suffered the effects of the hydrometeorological events, the impact was less due to its greater stability over climatic conditions (Ureta et al., 2020). And, even though research suggests that temperature has not a great influence on irrigation yields, its dependence on water availability -which in turn requires precipitation-, makes them more vulnerable to changes in the environment (Montesillo-Cedillo, 2016; Ureta et al., 2020).

Nevertheless, negative impacts on yields due to temperature increases and variations in precipitation are a fact; they have already been observed during the last years and, on average, more than 90% of losses in Mexican agriculture are related to drought conditions (Appendini &Liverman, 1994; Ureta, 2020). According to the Secretariat of Agriculture (SAGARPA), through its SIAP (2020) portal, the damaged area attributed to weather events and pests has been volatile during the analyzed period, with its extremest recorded impact in 2011 due to a decrease in precipitation. This event registered damages of over 3.5 million crops hectares (2.8 million for rainfed crops) and more than 7.8 million tons of yield (2.5 million attributed to rainfed harvest), implying losses for the agricultural sector of 28,088 million pesos or 7.9% of the total value of the harvested product for 2011 (see **graph 4.4.1 – 4.4.2**).

Moreover, adding add up the damages derived from climatic events during the 2000-2019 period, we have that 6.23% of the sown areas (27 million hectares), 0.52% of the production volume (57 million tons), and 1.82% of the total value of crops (127 billion pesos) were lost due to excess or shortage of rainfall, hail, and extreme temperatures (see **graph 4.4.2**). And, despite the losses related to climatic conditions vary year-to-year, they have presented a slightly negative trend that could be attributed to the increases in irrigation crops that are way more productive.

However, when the tipping point is reached, that is, when more frequent droughts jointly with extreme temperatures begin to reduce water availability and soil moisture -threatening yields of irrigation crops-, there would be a considerable increase in water demand that could lead to water stress and reverse the current trend (Liverman & O'Brien, 1991).

Graph 4.4.1. Crop loss due to climatic events and pests in Mexico (2000-2019)

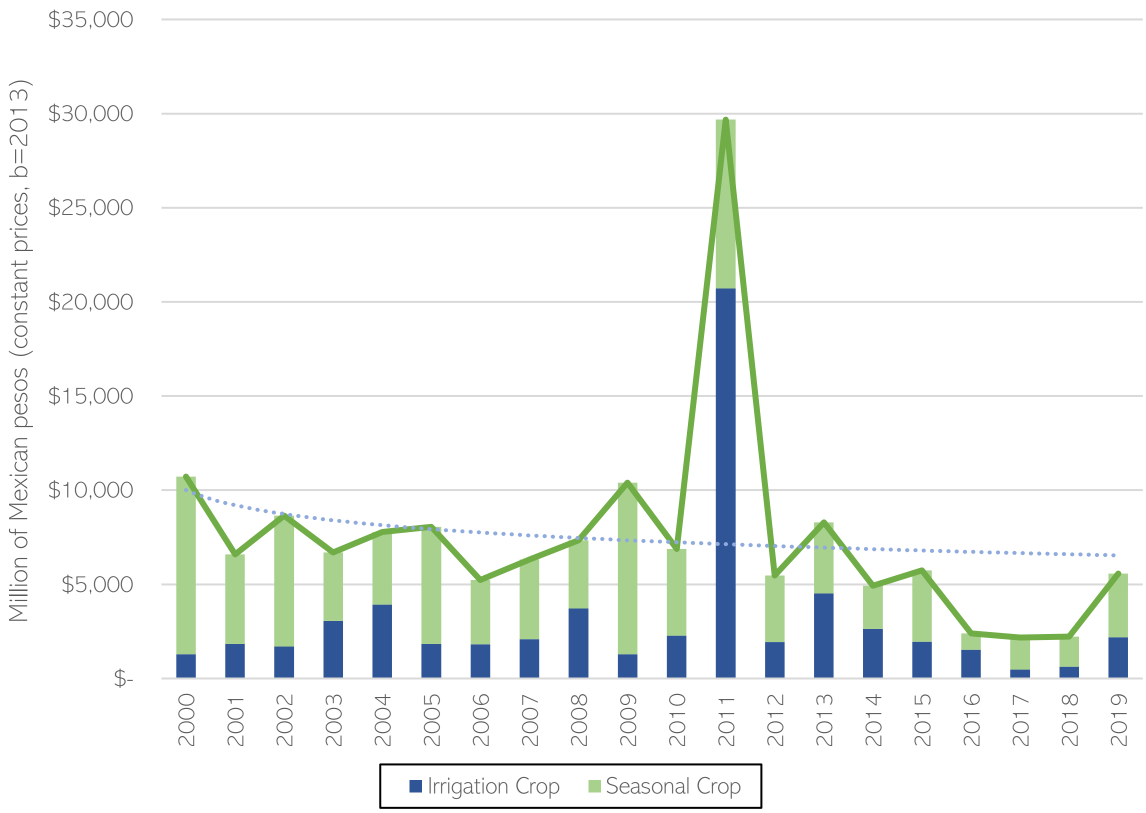


Source: Own elaboration based on data from SIAP, Mexico. 2020.

For a complete analysis, it might be better to disaggregate by type of crop because each depends on different conditions for its harvest, which are not produced in the same amount. For example, maize requires mean temperatures from 18 to 24°C and/or precipitation from 700 to 1,300 mm for an optimal yield (SAGARPA, 2017). Also, it represented 34.63% of the total harvest area recorded in 2019 (75.86% was harvested in rainfed fields and 24.14% in irrigation fields), becoming the most important crop due to its frequent consumption in the Mexican diet. For this reason, several articles try to analyze its relationship with climatic variables to consider the impacts of climate change on maize yields and its further consequences.

The different results coincided that maize yields are strongly correlated to rainfall rates at the national level. That is why during 1997-1998, the low precipitation led to a 25% decrease in maize's total production (Challenger, 1998; Murray-Tortaloro, 2018). Murray-Tortaloro et al. (2018) also mentioned that in 2011 the country faced a severe decrease in precipitation, which resulted in a decline of around 50% of maize yields.

Graph 4.4.2. Economic losses in the agricultural sector in Mexico (2000-2019)



Source: Own elaboration based on data from SIAP, Mexico. 2020.

4.5. Health costs

According to INECC (2006), the impacts on health that are related to climate change in Mexico are mainly due to extreme weather events, infectious diseases, and diseases transmitted by vectors, water, or food; such as: dengue, paludism, acute respiratory infections, heatstroke, and infectious intestinal diseases.

Regrettably, due to data limitations, just dengue and respiratory infections for PM_{10} concentrations will be analyzed. However, these diseases are relevant in this work because Mexico is more prone to present endemic vector-borne diseases and contribute to the development of new ones due to environmental changes. At the same time, some population groups are more susceptible to suffer from respiratory infections, which tend to rise with the interaction of atmospheric pollutants and rising temperatures (INECC & INSP, 2006).

- **DENGUE**

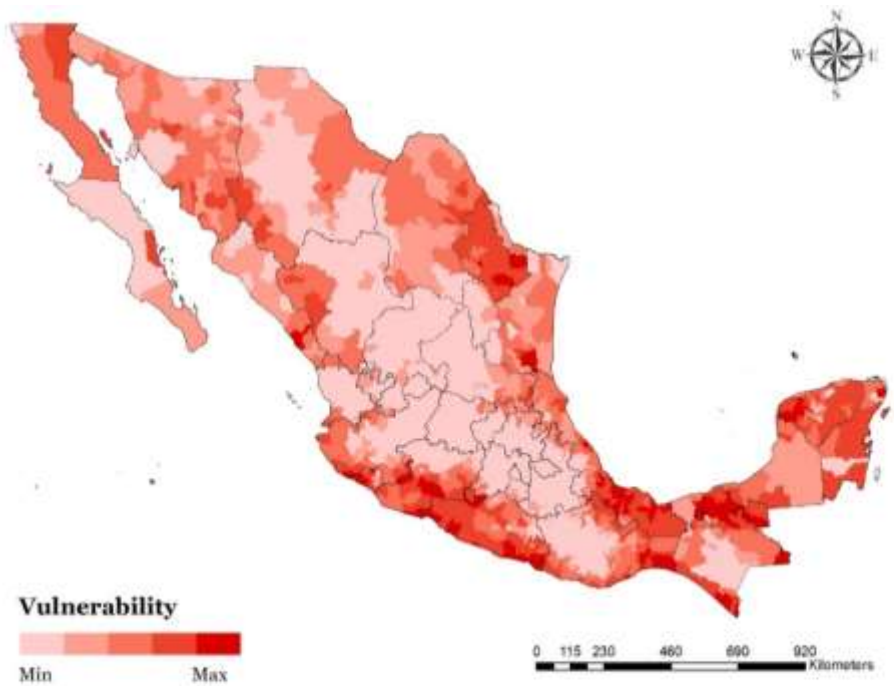
Dengue is a worrying vector-borne disease that has been increasing its number of confirmed cases and could affect even more regions if the temperature continues to increase. In 2019 there was a global increase in dengue incidence, and some scientists attribute this phenomenon to increases in global temperature –which increases the vector habitat–, the lack of treatments on the water to reduce the presence of mosquitoes, population growth, and migration (Arredondo et al., 2020).

Nowadays, dengue remains one of Mexico's main public health problems due to its impacts on morbidity, mortality, and the economy. Also, because the risks involved in dengue burden disease could be exacerbated by climate change, the National Atlas of Vulnerability to Climate Change (INECC) estimates the population's current vulnerability to the increase in the distribution of dengue by municipalities.[18]

As shown in **graph 4.5.1**, the Mexican coastal areas are categorized as extremely vulnerable to this disease. Particularly, this is consistent with recently published data by SUIVE stating that some entities like Jalisco, Nayarit, Guerrero, Colima, Chiapas, Quintana Roo, and Veracruz have exceeded the record for the number of newly reported cases of Dengue during 2019.

[18] For more information, visit: https://atlasvulnerabilidad.inecc.gob.mx

Graph 4.5.1. Current vulnerability of the population to the increase in the distribution of Dengue by municipalities



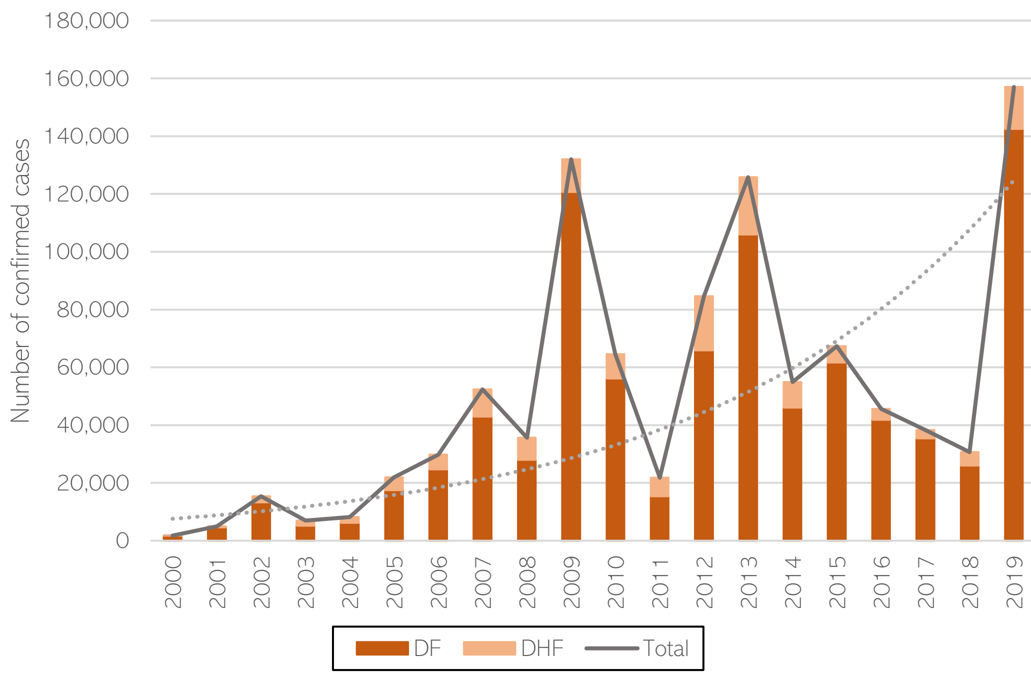
Source: Own elaboration with data from INECC (2019), National Atlas of Vulnerability to Climate Change

Current vulnerability considers three criteria: adaptation, sensibility, and exposure. Each variable sum up other components, like: population entitled to health services, urban infrastructure, public services, and current and projected exposure.

According to the General Directorate of Epidemiology (DGE), during the 2000-2019 period, there have been reported more than 900,000 confirmed cases, and we have seen new sprouts during 2007, 2009, 2012, 2013, and 2019 (see **graph 4.5.2**). Additionally, the incidence rate of Dengue Fever (DF) has increased from 1.72 to 112.56 cases per 100,000 inhabitants during the same period, while the incidence of Dengue Hemorrhagic Fever (DHF) went from 0.07 to 11.49 cases per 100,000 inhabitants.

Nevertheless, the increase between consecutive years usually varies because this disease has a dynamic behavior and, despite the continuous efforts to mitigate and control the transmission of Dengue, there are climatic patterns -mostly daily means temperatures and the temperature variation- that contributed to the current distribution of this virus and coincided with the regional outbreaks (Ebi & Nealon, 2016; Arredondo, 2020).

Graph 4.5.2. Incidence of Dengue Fever and Dengue Hemorrhagic Fever in Mexico (2000-2019)[19]



Source: Own elaboration based on data of Secretaría de Salud and SUIVE, 2020.

This evidence points out that Mexico has a relatively high dengue incidence that has dramatically increased in the last decades, and its geographical range has extended (Undurraga et al., 2015; Tiga et al., 2016). Therefore it must imply a major cost for the national healthcare system and for households where symptomatic patients are confirmed.

However, there is limited available data, so to get an estimate of the economic cost of dengue, I will use the Undurraga et al. (2015) methodology based on the following equation:

$$\begin{aligned}&\textit{Economic impact of dengue}\\&\quad = \textit{total episodes x costs por episode}\\&\quad + \textit{dengue prevention and surveillance activities}\\&\quad + \textit{other economic impacts}.\end{aligned}$$

[19] It should be noted that for this analysis the number of incidences will be use because it allows to measure throughout a determined period the number of registered infectious diseases in days or weeks, and because dengue has short-term effects, we are interested in its incidence and not prevalence.

The costs per dengue episode include direct and indirect costs using macro-costing techniques. Direct costs consider medical unit costs associated with diagnostic, medication, and treatment for outpatients and hospitalized patients. Also, they consider some non-medical costs as direct costs, for example: food, transport, and accommodation expenditures. Indirect costs have a human capital approach because they consider losses in productivity and working or school days for patients and caregivers. Moreover, vector control and surveillance costs are also included in the study at a federal level, and the estimates are based on the annual budget for epidemiological surveillance and control approved by the Federal Expenditure Budget (PEF). Nevertheless, other economic impacts of this disease are not considered, for example: the long-term complications of dengue, the impacts of outbreaks in tourism revenues, or the effects of health system overload due to resource and equipment limitations (Zubieta & Zavala., 2018).

For the stated purposes, the average cost per episode results from Undurraga et al. (2015) research (see **table 4.5.**), the number of confirmed cases reported by the Dengue Epidemiological Outlook, and the approved budget for epidemiological surveillance and control by the Ministry of Finance (SHCP), were used.

Table 4.5. The average cost per dengue episode

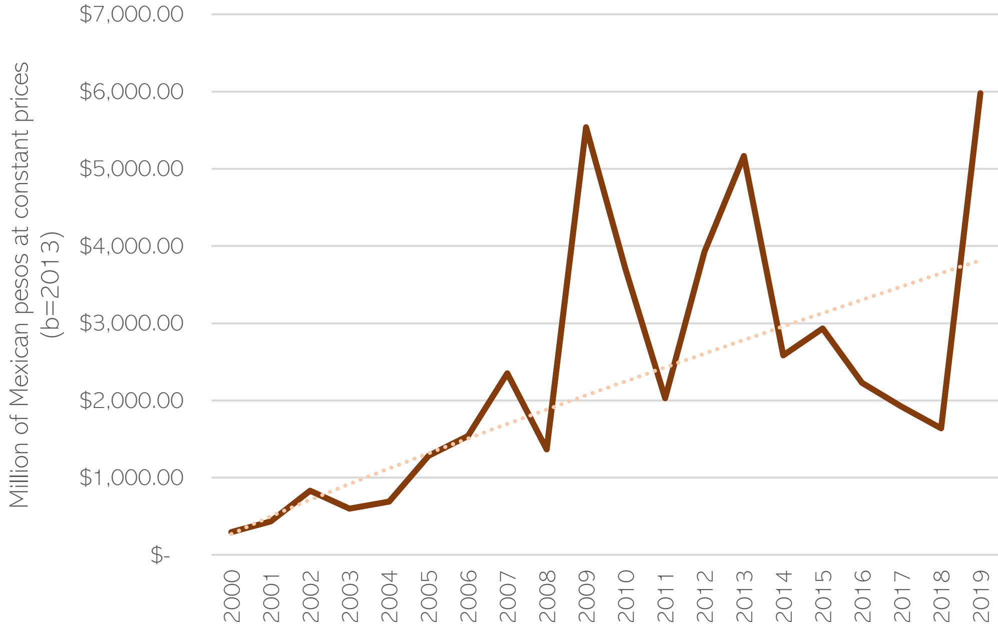
	Hospitalized Patients	*Ambulatory Patients*	*Fatal cases*
2012 US dollars	1,327	451	63,817
*2013 MX pesos**	17,091.76	5,808.88	821,962.96

Source: Undurraga, et al. (2015) Economic and Disease Burden of Dengue in Mexico. PLoS Negl Trop Dis 9(3): e0003547. Doi:10.1371/journal.pntd.0003547. p. 12.

**Using the 2012 exchange rate (USD1=12.88 MXN) as well as GDP deflators to report results in 2013 MXN pesos.*

Graph 4.5.3. shows the economic impact of dengue virus infection in Mexico for 2000-2019, according to the beforementioned assumptions. The results reveal how the costs are proportional related to the number of confirmed cases, but also the approved budget for epidemiological prevention and control is relevant. In addition, the largest impacts coincide with the incidence outbreaks, where 2019 performs as the worst year in terms of dengue economic cost for the Mexican economy because it more than doubles the annual average of MX $ 2,352 million pesos.

Graph 4.5.3. Annual Economic Cost of Dengue in Mexico (2000-2019)



Source: Own elaboration with data from Undurraga et al. (2015), Secretaría de Salud, SUIVE (2020).

Estimates were obtained using average costs per-case of Dengue reported by Undurraga et al. (2015). As the number of hospitalized and ambulatory dengue patients is not registered in any public governmental database, it was taken as an assumption the average reported in Undurraga et al. (2015), where 16% of DF and 80% of DHF confirmed cases were hospitalized. I also adjust for all symptomatic Dengue Virus infections -using an expansion factor of 2.0 for ambulatory and fatal cases and 5.6 for ambulatory cases-, since many reports have indicated an underestimation in confirmed cases.[20]

- **ACUTE RESPIRATORY INFECTIONS**

Climate change impacts human health by affecting immunological and respiratory systems. But, when it comes to threats to respiratory health, it is important to consider air pollution due to its effects on mortality that has increased along with the rise in atmospheric concentrations. Furthermore, climate change, along with air pollution, represents a hazard for respiratory health by aggravating or allowing the development of respiratory diseases and by increasing the exposure to risk factors for these diseases, as it is: asthma, rhinosinusitis, chronic obstructive pulmonary disease, and respiratory tract infections (D'Amato et al., 2014).

[20] For more information check out: Undurraga EA, Betancourt-Cravioto M, Ramos-Castañeda J, Martínez-Vega R, Méndez-Gálvan J, Gubler DJ, et al. (2015) Economic and Disease Burden of Dengue in Mexico. PLoS Negl Trop Dis 9(3): e0003547. Doi:10.1371/journal.pntd.0003547.

In particular, health problems are attributed to air pollution by $PM_{2.5}$, PM_{10}, NO_2, and ozone concentration. And, it has been estimated that $PM_{2.5}$ has the greatest impact on health and the economy associated with rises in work absences. Specifically, the estimated annual economic impact attributed to air pollution in Mexico by adverse effects on human health amounts to USD$29 billion and 51,000 premature deaths for 2018 (Farrow et al., 2020).

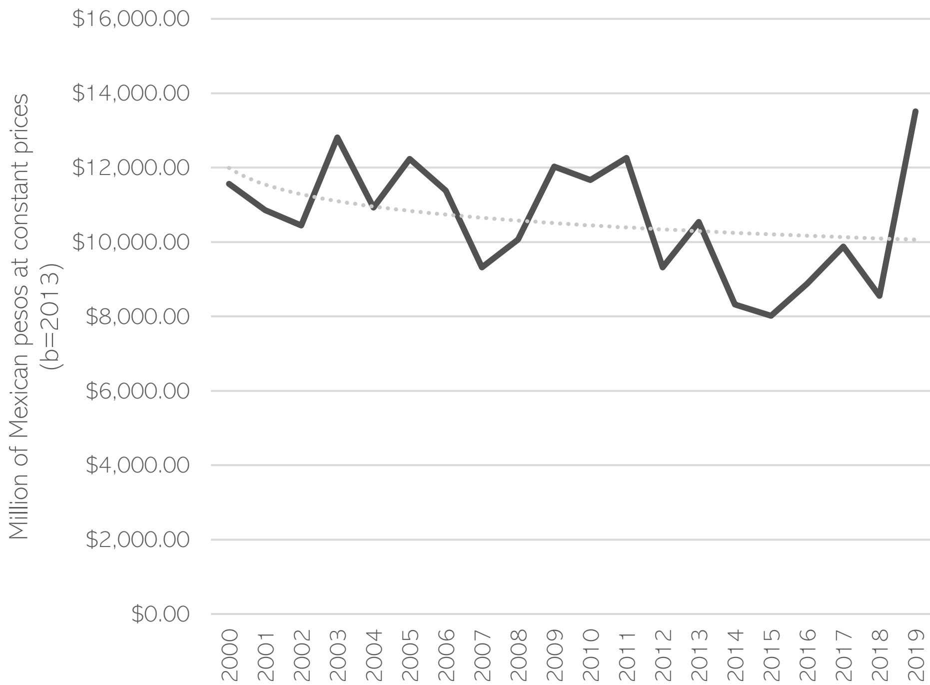
However, human health can also be affected by PM_{10} particles emitted by combustion processes in automobiles, industrial activities, and forest fires. For this reason, the Mexican Institute for Competitiveness (IMCO) has developed a methodology to estimate the health costs of poor air quality related to PM_{10} particles, as costs related to health systems and losses in productivity.[21] And, for the purposes of this research, I will use this methodology with data from INEGI, SSA, IMSS, SEMARNAT, and INECC to estimate the economic costs related to air pollution by PM_{10} particles for the period 2000-2019.

The results obtained from the model are the number of deaths, hospitalizations, and medical consultations attributable to air pollution by the type of disease: respiratory infections, cardiovascular diseases, and respiratory diseases. Subsequently, the economic cost is calculated when multiplying by productivity losses, the daily cost of hospitalization, and the cost of a consultation, respectively. Nonetheless, estimations turn out to be conservative due to the assumptions. Firstly, because we only consider the concentration of one pollutant in the atmosphere, PM_{10} particles. Secondly, because the analysis considers the 34 most populated cities in Mexico and we assume that the population has similar characteristics and behaviors. And, finally, because hospital discharges and medical consultations at the municipal level are distributed at the same rate as 2010 levels due to a lack of information.

As shown in **graph 4.5.4**, the health costs related to air pollution are susceptible to fluctuations related to the concentration of particles PM_{10} in the atmosphere and the incidence of acute respiratory diseases, which in recent years tended to decrease (see **graph 4.5.5**). That is why we can see a negative trend in these costs, which also could be driven by the recent deceleration of GHG emissions in Mexico.

[21] For more information about IMCO methodology, visit: ¿Cuánto nos cuesta la contaminación del aire en México? (2013). Retrieved from http://imco.org.mx/wp-content/uploads/2013/09/Anexo-Metodol%C3%B3gico-24Sep13.pdf

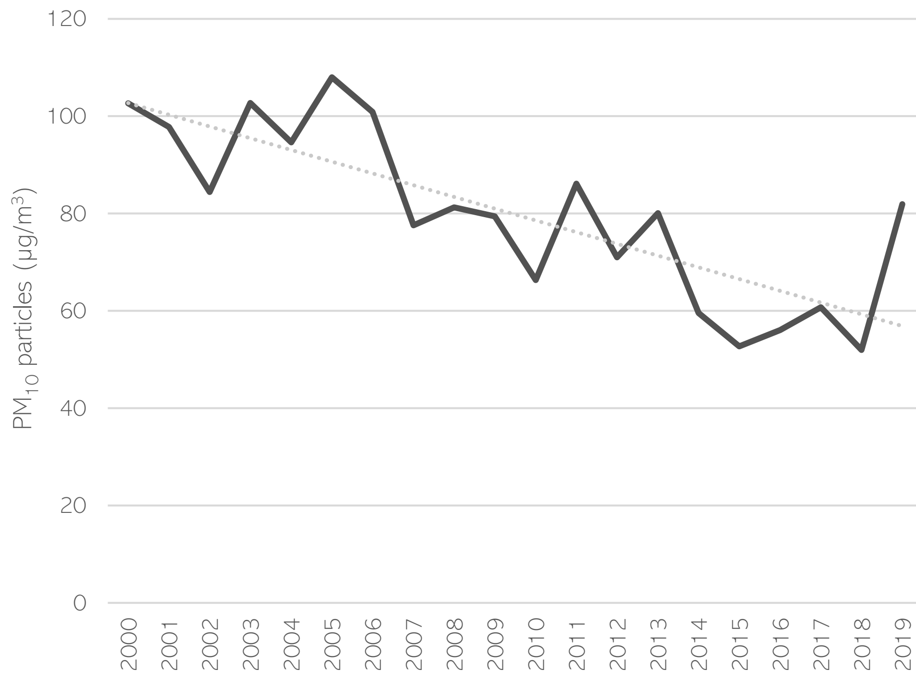
Graph 4.5.4. Annual Economic Cost of Air Pollution in Human Health (2000-2019)



Source: Own elaboration following IMCO (2010) methodology with data from INEGI, SSA, IMSS, SEMARNAT, and INECC (2020).

In summary, the health impacts related to air pollution by particles PM_{10} costs the Mexican economy an average of $10,630.03 million of Mexican pesos and 7,704 premature deaths. While during the recorded period, they have caused an accumulated cost that amounts to $212,600.57 million pesos and 154,083 deaths.

Graph 4.5.5. Annual average concentrations of PM_{10} (2000-2019)



Source: Own elaboration with data from INECC (2018), Informe Nacional de la Calidad del Aire.

4.6. Economic costs of climate change

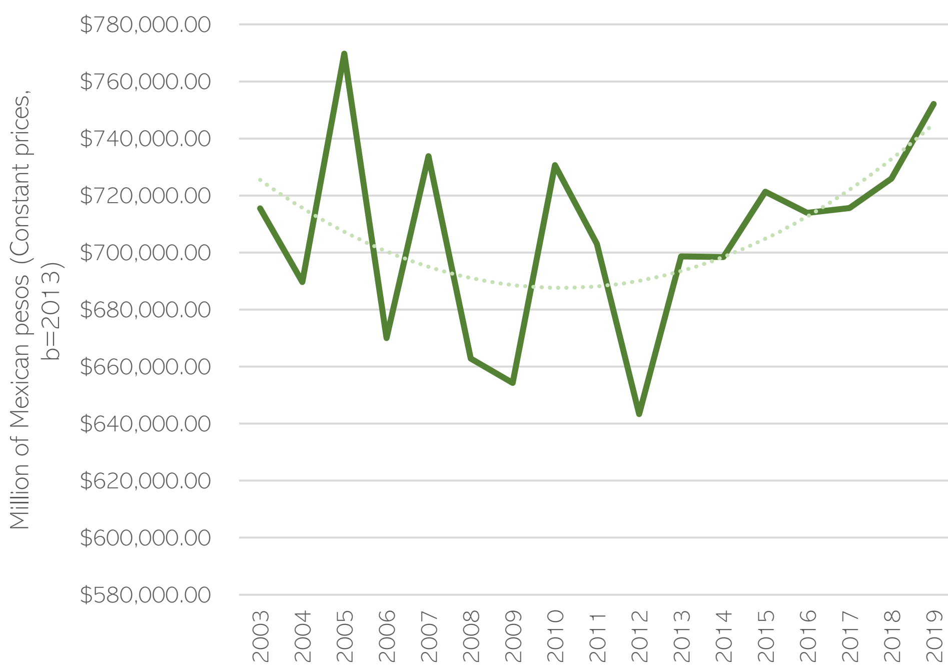
The sum of the direct costs of climate change damage was decreasing during the first reported periods (2003-2012), but since 2013 they started to register a continuous acceleration. That is why a trend with a "U" form can be observed. In addition, it is noted that the reported costs vary between the $640 – $770 billion pesos, with the largest record in 2005.

Furthermore, the higher costs of climate change result from environmental degradation. These costs have accounted for about 80 – 96% of total costs and are attributed to damage by economic activities to environmental quality (related to water pollution, air pollution, and land degradation). Followed by these costs are those attributed to tropical cyclones and other extreme natural events (rainfall, flooding, landslides, storms, and forest fires). All of these are characterized by being extremely volatile. This is attributed to the uncertainty in the variability of climatic stressors and thus extreme natural events. But also, each locality has a different degree of vulnerability to these events (which depends on exposure, sensitivity, and adaptation), which implies different types of damages. Besides, these climatic events have presented between 0.9 - 13% of the total damages. Although, on average, 2.11% of the total costs are associated with tropical cyclones and 1.72% with costs due to the impact of other extreme events.

Moreover, losses in agriculture and costs related to health effects from PM_{10} particles contribute, on average, 1.05% and 1.5% to total costs, respectively. And, specifically, these health costs have been more constant in the reporting period, while agriculture costs have been relatively variable, recording the worst losses in 2011 due to droughts.

Finally, health damage from the most common vector disease, dengue, has contributed the least to the economic costs of climate change. However, it shows a positive trend that has led to an increase in its share in total costs from 0.08% to 0.79%, an increase of almost 900%.

Graph 4.6.1. Direct costs of climate change damage (2003-2019)

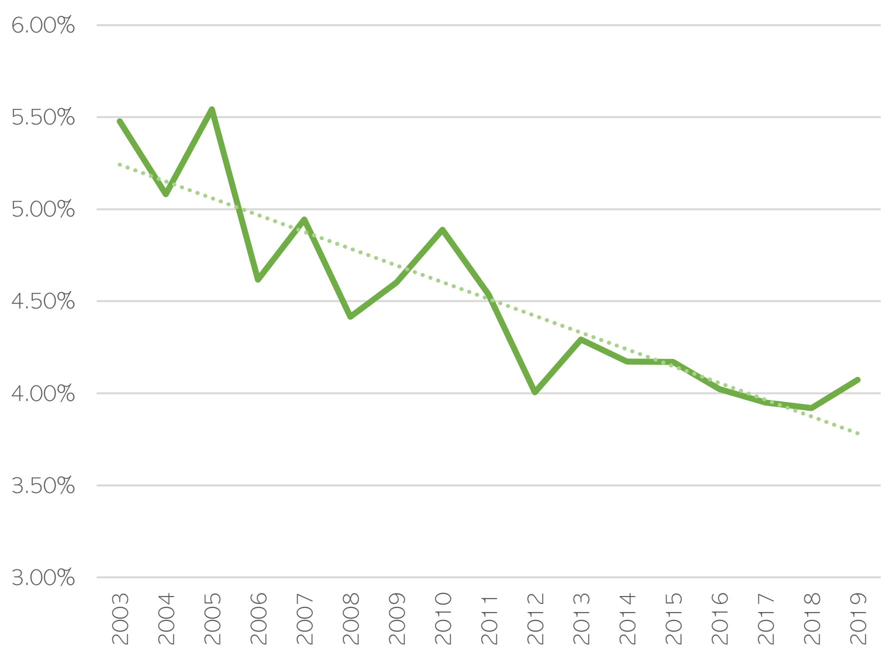


Source: Own elaboration. It corresponds to the sum of the economic costs presented in the previous sections.

Furthermore, it has been noted that although the economic costs resulting from the damages of climate change show a growing trend since 2013, their share in terms of GDP has decreased by 1.41 percentual points. Thus, a negative trend is observed. Also, the annual average direct costs of climate change damage represent 4.5% of the GDP. Where 2005 was the year with the highest costs in terms of GDP. While 2018 reported a ratio of 3.92%, the lowest cost recorded during the 2003-2019 period.

Nevertheless, even observing this downward trend of climate change's damage costs as a percentage of GDP, no one can guarantee that it will continue in the coming years. It could be reversed given that the COVID-19 pandemic has strongly damaged GDP in Mexico. Also, because during 2020, record-breaking cyclone formations in the Atlantic and devastating natural phenomena in the south of the country were recorded. At the same time, we have seen a setback in environmental policies by the current administration.

Graph 4.6.2. Direct costs of climate change damage as a % of GDP (2003-2019)



Source: Own elaboration. It corresponds to the sum of the economic costs presented in the previous sections.

CONCLUSIONS

In this thesis, I have focused on identifying the damages and risks involved in the Mexican economy. According to SEMARNAT, the effects of climate change that have already been observed in Mexico are: increase in temperature during the last century; the variations in rainfall patterns; forest fires; loss of important glaciers; more frequent impacts of extreme natural events; droughts; and, sea-level rise in coastal areas. All of these have involved threats and damage to natural resources, the environment, and human health.

However, due to data availability and time restrictions to analyze the direct costs of climate change damage, the following events' were considered: a) impacts of tropical cyclones and other extreme natural events; b) damage to agriculture; c) environmental degradation; and d) health impacts. These events had negative effects on the economy, involving risks and damage to infrastructure, human health, food security, labor productivity, and economic development. In addition, the combination of these costs has implied the need to look for alternatives in growth to be consistent with sustainable development.

Furthermore, the aggregation of costs arising from climate change shows us that the greatest impact is received by the costs of degradation. The later type of damage has accounted for about 80-96% of the total costs and is composed by the costs that society would have to incur in order to prevent or remedy the damage to the environmental quality attributed to economic activities. Followed by these costs are those attributed to the damage of tropical cyclones and other extreme natural events (rain, floods, landslides, storms, fires), which are characterized by being extremely volatile. This is because the magnitude of change in climate stressors is not predictable, so neither are extreme natural events. Likewise, these climatic events have represented between 0.9-13% of the damage.

About the economic costs arising from losses in agriculture and health impacts, jointly, they contribute around 2.9% to total direct damages. However, they are significant, and as the temperature continues to rise, there could be increases in their impacts, as is the case of the costs of dengue, which have shown accelerated growth during the reporting period.

Finally, the sum of these direct costs attributable to climate change damages shows a positive trend since 2013, where it started to present accelerated growth rates, and for 2019 it reaches costs for $752 billion Mexican pesos, the second-largest amount. Besides, the annual average cost of climate change damage is $705 billion Mexican pesos. Nonetheless, direct costs of climate change damage as a percentage of GDP have tended to decline during the reported period, with a reported annual average of 4.5%.

In sum, considering the three established hypotheses in the introduction, this work shows that the direct costs of climate change damage have been growing in a long-run trend, but with notorious ups and downs, as expected in the first hypothesis. The results also let us support the second hypothesis, which confirms that the direct costs of climate change damage as a GDP ratio have dropped during the 2003-2019 period; nonetheless, this fall has been slow. It should be stronger in the future in order to prevent larger indirect damages as they are result of direct ones. Finally, the findings reinforce hypothesis 3, since the direct damages of climate change have concentrated in a particular type of damage, which is environmental degradation, predominantly air pollution.

Limits and research areas

Climate change is becoming a central issue due to all the implication it has in different sectors. However, as a phenomenon with a lot of uncertainty in its effects, there are still many limitations in data and scientific evidence. But, instead of being taken as a limitation, this can be used to develop more research. Specifically, in the economic area, I believe that it would be important to continue working on identifying costs and vulnerabilities with the objective of designing mitigation and adaptation policies.

In addition, as we have seen, this work focused only on the direct costs of climate change damage, so it would be interesting to address the indirect costs and their socioeconomic impacts in Mexico. At the same time, it leaves us the possibility of developing tools that allow us to obtain approximations of the non-monetary costs, which undoubtedly affect the economy.

Finally, in the interest of improving this work and pursuing lines of research, an opportunity could be to analyze why direct costs as a percentage of GDP have tended to decrease in Mexico. If it is due to better adaptative capacity, the structure of damage or volatility that characterizes these costs, among others. At the same time, we can consider using in the future better methodologies that can integrate other factors that were not taken into account through Integrated Assessment Models or a Factor Attributable Risk, that would allow us to better approximate costs attributable solely to climate change, without taking into account the natural variations that have a historical presence.

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