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INSTITUTO NACIONAL DE ECOLOGÍA Y CAMBIO CLIMÁTICO

MACROECONOMIC RISK PROFILE: MEXICO

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TECHNICAL ADVISORY SERVICES FOR THE PREPARATION OF GCF COUNTRY PROGRAMMES

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Climate Analytics (CA) is an international non-profit climate science and policy institute headquartered in Berlin, Germany with regional offices in Lomé, Togo, Perth, Australia and New York, USA and with associates across Europe, South America, Asia, Africa, the Pacific and the Caribbean.

International Institute for Applied Systems Analysis (IIASA) is an international scientific institute that conducts policy-oriented research into problems that are too large or too complex to be solved by a single country or academic discipline.

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Macroeconomic risk profile: Mexico

Under the project **Technical Advisory Services for the Preparation of GCF Country Programmes.**

This study is carried out under the Green Climate Fund (GCF) technical advisory service which is aimed at providing technical expertise to enhance the quality of Country Programmes. The primary objective of the service is to produce high-quality, relevant and independent analysis on the climate change risks, adaptation and mitigation opportunities each country faces. With a strong country ownership being embedded in the whole engagement process, the technical outputs, including the present study, are most likely to be fed into the Country Programme and/or other climate planning processes underway, such as updating NDCs, and is intended to be complementary to other GCF readiness activities being undertaken within each country as well as other national efforts in climate change research.

In particular, this report seeks to identify future climate change risks for specific economic sectors as well as overall GDP growth. The report thus contributes to identifying high-risk areas and to developing risk narratives, which in turn can be a valuable input for priority setting of adaptation options.

The results presented here are a combination of research from existing publications, consultations with the NDA and INECC, and country-specific econometric methods using up-to-date datasets aimed at providing the country with the results of a simple model to assess the economic impacts of climate change under a 1.5°C Paris Agreement-consistent scenario, a 2°C scenario and a scenario consistent with current NDCs (3°C – see e.g. UNEP 2020) [18].

Prepared under the guidance of:

Mexican Federal Ministry of Finance and Public Credit (**Secretaría de Hacienda y Crédito Público, SHCP** by its initials in Spanish), Mexico.
National Institute of Ecology and Climate Change (**Instituto Nacional de Ecología y Cambio Climático, INECC** by its initials in Spanish), Mexico.

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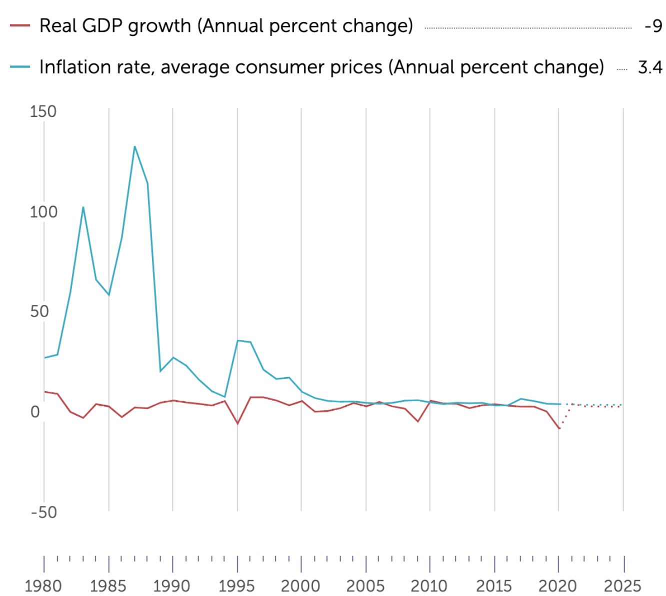
GLOSSARY

CDD	Consecutive Dry Days
CVA	Climate Vulnerability Assessment
GCF	Green Climate Fund
GCM	Global Climate Model
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GVA	Gross Value Added
INECC	National Institute of Ecology and Climate Change
NAFTA	North American Free Trade Agreement
NDA	National Designated Authority
NDC	Nationally Determined Contribution
RCP	Representative Concentration Pathway
RX5	Maximum consecutive 5-day precipitation
SPI	Standardized Precipitation Index
SSP	Shared Socioeconomic Pathway

1. INTRODUCTION

Mexico is among the 15 largest economies in the world, and the second largest in Latin America [1]. After a series of economic shocks in the 80s and 90s, the country undertook deep structural reforms, including privatization, deregulation, and trade liberalization. The North American Free Trade Agreement (NAFTA) signed in 1993 opens the financial sector to foreign participation and enhances trade. However, despite the stabilization in the monetary and financial sectors, Mexico continues to experience subdued economic growth and slow progress in poverty reduction. As of 2018, 49 percent of the population is considered poor, and the country's Gini index is 45.4[1]. Mexico has also been strongly affected by the COVID-19 pandemic, which has cost more than 75,000 lives, caused about 12 million employees to lose their jobs, and is expected to worsen poverty rates. Mexico's economy is estimated to contract in 2020 by 9 percent, with inflation hovering around 3.4 percent [2].

Figure 1. Mexico's real GDP growth and inflation rate, annual percent changes (1980-2020). Real GDP growth in 2020 was minus 9%, the inflation rate in 2020 was 3.4%.



Source: IMF DataMapper, October 2020, https://www.imf.org/external/datamapper/NGDP_RPCH@WEO/OEMDC/ADVEC/WEOWORLD.

The climate in Mexico has regional variations due to the variety in topography and location. In the central and upland areas, average annual temperatures range from 15°C to 20°C, whereas in the coastal lowland areas temperatures

[1] Poverty headcount ratio at national poverty lines (% of population) and Gini index representing 0 as perfect equality, and 1 as perfect inequality. Source: World Bank data (World Development Indicators). Accessed on 04 November 2020.

average between 23°C to 27°C. In terms of precipitation, regions located in the north experience much drier seasons throughout the year, with an average rainfall of less than 50mm per month, while central and southern regions experience a wet season during the months of June to October with about 550mm per month of rainfall [3].

1.1. Exposure and vulnerability to Climate Change

On top of the socioeconomic challenges of Mexico, its development is constantly threatened by climate change impacts, which will have implications on the state of income inequality and poverty in the country. Mexico is located between the Atlantic and Pacific oceans, which expose it to extreme events such as tropical cyclones, frosts, heatwaves, and flooding; as well as the effects of the El Niño-Southern Oscillation on the intensity of the extreme events [3].

1.2. Infrastructure

The highly populated urban areas with a large proportion living in informal settlements, as well as the aging transportation, power and water infrastructures are highly vulnerable to extreme events, particularly hurricanes, flooding, and landslides. Urban areas are particularly prone to suffer from an urban heat island effect which is typically aggravated by a low share (or even absence) of vegetation and green areas and a high density of buildings [5]. An increased need for cooling (e.g. air conditioning) can furthermore aggravate the heat accumulation in the streets. Heatwaves would likely stress power plants due to the increase in demand for cooling systems to run and the suboptimal efficiency in operating in higher temperatures [3].

1.3. Tourism

Tourism is affected by both rising temperatures and extreme events. Summer tourism at the coast (i.e., states of Veracruz, Tabasco, Campeche and Quintana Roo) are directly affected by hurricanes, heavy rainfall, storm surges, and strong winds; as well as rising sea levels [3]; while rising temperatures affect snow levels and icecap glacier volumes that drive winter tourism. Warmer temperatures also result in higher cooling costs, tourist thermal stress, as well as coastal erosion and coral bleaching which have implications for the attractiveness of diving and snorkeling destinations and increase the cost of protecting these resources [7][2].

[2] Cited from UNWTO (2008) in the report.

1.4. Health

Mexico is also affected by further warming through health impacts. Exposure to extreme heat has been shown to be linked to increased mortality as well as morbidity [15]. In particular, the incidence of heat strokes might increase by as much as 47% [5]. In addition, rising temperatures and changing precipitation patterns are projected to increase the spread of vector-borne diseases [7]. Furthermore, declining agricultural productivity is likely to lead to additional health impacts through adverse impacts on food security [3].

1.5. Employment

Higher temperatures are widely known to reduce labor productivity either through adaptation measures that require individuals to take more breaks to regulate body heat or, in the worst case, loss in actual labor due to heat-related illnesses [12][13][14]. In addition, in the case of Mexico, extreme temperatures also increase the probability of out-migration. Rising temperatures and reduced water supplies are likely to lead to reduced crop and livestock productivity [3] and thus a declining agricultural income earning potential. In turn, migration from rural to urban areas within the country is expected to rise (probability increase from 0.7 to 1.4 percent)[3] [11]. Similarly, migration to the US is equally projected to see a probability increase between 0.05 and 0.25 percent [11].

1.6. Climate Action

Global inaction to climate change could cost Mexico between 550 billion to 2.3 trillion dollars[4] in 2100, while limiting global warming to 1.5°C relative to preindustrial times could reduce the accumulated costs to 210-770 billion dollars. The calculated cost of inaction in 2030 exceeds the cost of implementing the 30 mitigation measures (which are in line with the NDCs) by about 17 billion dollars [5].

In 2016, Mexico had submitted its mid-century strategy to the UNFCCC, pledging to reduce its national Greenhouse Gas (GHG) emissions by 50% in 2050 relative to the year 2000. The policies focus on five key areas: clean energy transition, energy efficiency and sustainable consumption, sustainable cities, reduction of short-lived climate pollutants and sustainable agriculture, and protection of natural carbon sinks [6]. In December 2020, Mexico has submitted an update to their 2015 Nationally Determined Contributions (NDC) stating that it would unconditionally

[3] Jessoe et al. (2016) uses a medium emissions scenario where the Growing Degree Days and Harmful Degree Days are predicted to increase by 226 and 6 days, respectively.

[4] In today's dollar value equivalent.

commit to reducing its GHG emissions by 22% by the year 2030 compared to a business-as-usual (BAU) emission baseline [17].

2. METHODOLOGY AND DATA

2.1. Methodology

The macroeconomic risk profile estimates the impact of a climate shock to the overall economy. To obtain projected future aggregate economic impacts, we follow a three-step approach. First, we estimate the historic impact of temperature and precipitation changes on economic activity at a meso-region level for the three sectors Agriculture, Industry and Services. Second, we combine these estimated impacts with climate model projections to obtain projected future impacts by sector at the mesoregion level. Finally, we combine the sectoral impacts in a bottom-up approach for the estimation of GDP impacts. These three steps are explained in the following section.

This analytical approach implicitly takes the following assumptions. In order for the overall GDP impacts to match the aggregated sectoral impacts, we assume the sectoral shares to remain constant over time. Furthermore, we use the Shared Socioeconomic Pathways (SSPs) for our projection exercise (see below for a more detailed description). Implicit in the SSPs are assumptions on population growth, access to education, urbanization, economic growth, the availability of resources, technological development as well as changes in lifestyle[5].

2.1.1. Historical estimation of impacts

In consideration of the spatial resolution of the climate data which would not be able to differentiate between climates in states, we refer to the mesoregions developed by the Ministry of Communications and Transport[6], as the main administrative division in this study:

- **Northwest:** Baja California, Baja California Sur, Sonora and Sinaloa.
- **Northeast:** Chihuahua, Coahuila, Nuevo León, Tamaulipas and Durango.
- **Central-West:** Nayarit, Jalisco, Colima, Michoacán, Zacatecas, Aguascalientes, Guanajuato and San Luis Potosí.
- **Central:** Hidalgo, Querétaro, Tlaxcala, Morelos, the State of Mexico and Mexico City.

[5] https://www.carbonbrief.org/explainer-how-shared-socioeconomic-pathways-explore-future-climate-change provides a good explanation of SSPs.
[6] https://www.gob.mx/cms/uploads/attachment/file/67641/CAP-08.pdf

- **Southeast:** Puebla, Guerrero, Oaxaca, Chiapas, Veracruz, Tabasco, Campeche, Yucatán and Quintana Roo.

The economic data by state have been aggregated to the mesoregion level, while the climate data have been area-weighted to this level.

Once the datasets have been prepared, we conduct a panel regression of the reduced form

$$\ln GVA_{ist} = \alpha_0 + \alpha_1 T_{it} + \alpha_2 T_{it}^2 + \alpha_3 P_{it} + \alpha_4 P_{it}^2 + X_{it} + \mu_i + \varepsilon_{ist}$$

The dependent variable is the natural logarithm of the gross value-added (GVA) of mesoregion i, sector s at year t. Gross value added – the value of output minus the value of intermediate consumption – measures the contribution of an individual sector to GDP.[7] In the bottom-up approach employed in this report (see below), we can combine the GVA estimates for the individual sectors to estimate overall GDP impacts. The independent variables are the linear and squared term of mean annual temperature (T_{it} and T_{it}^2) and precipitation P_{it} and P_{it}^2 in mesoregion i and year t. In addition, we include a vector of control variables X to account for extreme events and changes over time: The maximum consecutive 5-day precipitation (RX5), the maximum length of a dry spell (CDD) as well as the Standardized Precipitation Index (SPI)[8] as meteorological drought measure. We also include a time trend variable as well as dummies for one-off events such as the Peso crisis in 1995 and the impact of the swine flu in 2009. The SPI values are translated into annual values to match the temporal resolution of the economic data by counting the number of months when SPI values show moderately dry (SPI values between -1.0 and -1.49), severely dry (SPI values between -1.5 and -1.99), and extremely dry (<-2.0) within the calendar year [19]. The SPI can be calculated for different time scales, e.g. 1 month, 3 months, 6 months and 12 months, reflecting different 'types of droughts'.[9]

For a discussion of the strengths and weaknesses of the SPI as well as the interpretation of the different time scales see WMO (2012) [19]. We include time-invariant fixed effects at the mesoregion level, μ_i. ε represent the idiosyncratic error term.

[7] https://stats.oecd.org/glossary/detail.asp?ID=1184

[8] We have considered four different time scales for SPI – 1 month, 3-month, 6-month, and 12-month.

[9] Meteorological conditions and soil moisture respond to deviating from normal precipitation pattern on comparably short time scales (e.g. 1 to 6 months). In contrast, streamflows and groundwater reservoirs are affected by longer-term precipitation deviations (e.g. 6 months to 24 months). Meteorological drought conditions are therefore best reflected by 1-2 months SPI conditions, agricultural droughts by 1-6 months SPI and hydrological drought conditions rather beyond 6 months to 24months SPI [19].

The panel regression was done separately for each sector. Due to the uncertainty of which SPI time scale and drought intensity matter for each of the sectors, an automation was made to randomize SPI combinations with the rest of the variables, creating a total of about 4,096 regression results for each of the sectors. The best model from the regression results was selected by, first, filtering results that had an adjusted R2 value of greater than the 99th percentile and a root-mean-square error (RMSE) term of less than the 1st percentile. This narrows down the number of models to about 40. Finally, a manual selection of the preferred model was made based on the t-test results for each of the relevant variables.

2.1.2. Impact Projections

The resulting coefficients from the historical regression model are applied to the change in climate projections under different warming thresholds, relative to the baseline scenario. The results of the impact projections are shown for impacts due to temperature changes only, precipitation only, and a combination of all variables[10]. Results at this point will be in percent change by economic sector and mesoregion.

2.1.3. Bottom-up Estimation of Impacts to GDP

Following the national income accounting by production, wherein the sum of the gross value-added of agriculture, industry, and services would amount to the total economic income, we apply the impact of climate change by sector and mesoregion (in percent) to monetary projections of GVA per sector and mesoregion (and state).

We refer to the GDP projections under SSP 2 as the middle-of-the-road scenario. Because a sub-national, sub-sectoral breakdown of projections are not available, we approximate the state-level, sectoral values in two steps: first, we take the GDP growth rates for all of Mexico in the SSPs, and apply these to the actual 2010 value, multiplied by the average share of each state's GDP to total GDP from 1985-2015; then, we take the estimated state-level GDP and multiply the average share of each of the sectors in the total state-level GDP. The main assumptions in this approximation are that there are no changes in the contribution of each state to the total GDP of Mexico, and there is no structural change happening within the states. The approximation results in GDP in constant 2013 million Pesos.

Once the monetary values have been approximated, we apply the climate change impacts (in percent) to the estimated GVA per sector per state (end-of-

[10] Due to the less frequent occurrence of extreme events and robustness concerns, we take caution in focusing on its impacts. They are, however, important to include as control variables.

century, in million Pesos). The total GDP impact is calculated by aggregating the sectoral, state-level impacts.

2.2. Historical Data

The economic data used in the regression analysis is the GDP of economic activities by state in constant 2013 Mexican Pesos from 1980-2018[11]. Two dummy variables have been added to the analysis – the Mexican Peso crisis in 1995 and the Swine flu in 2009 – which have created an observable disruption in production over the years. The climate data is taken from the GSWP3-W5E5[12], a global dataset used as an input for the Intersectoral Impact Model Intercomparison Project (ISIMIP). It is a combination of two datasets – W5E5 for 1979-2016 and GSWP3 for 1901-1978 – with a 0.5° x 0.5° spatial resolution and daily temporal resolution[13].

The climate variables considered in this analysis are the following:

- Mean annual temperature – average air surface temperature over the calendar year
- Annual sum of precipitation – Sum of average daily precipitation over the calendar year
- RX5day – Maximum consecutive 5-day precipitation [8]
- Consecutive Dry Days (CDD) – Maximum length of dry spell: maximum number of consecutive days with daily rainfall < 1mm [8]
- Standardized Precipitation Index (SPI) – Drought indicator, whose values represent the number of standard deviations by which the observed anomaly deviates from the long-term mean [9]

2.3. Projections Data

Climate projections are bias-corrected data taken from the latest generation of Global Climate Models (GCMs) from the Coupled Model Intercomparison Project Phase 6 (CMIP6) data archive. The climate projections under the different temperature thresholds are calculated using the 30-year average around the year when Representative Concentration Pathway (RCP)[14] 8.5 reaches 1.5°C, 2°C,

[11] Source link: https://www.inegi.org.mx/programas/pibent/2013/default.html#Tabulares. Data was updated on July 09, 2020.

[12] Source link: https://www.isimip.org/gettingstarted/input-data-bias-correction/details/80/

[13] To minimize discontinuities at the transition between the two datasets (1978/1979), the GSWP3 data provided by ISIMIP have been homogenized with the W5E5 dataset using a bias adjustment method. A detailed description of the bias adjustment method used can be found here: https://doi.org/10.5281/zenodo.3648654.

[14] RCPs (Representative Concentration Pathways) are greenhouse gas (GHG) concentration pathways adopted by the IPCC in its 5th Assessment Report [16].

and 3°C [10]. The baseline period is used to calculate the absolute change in the climate variables.

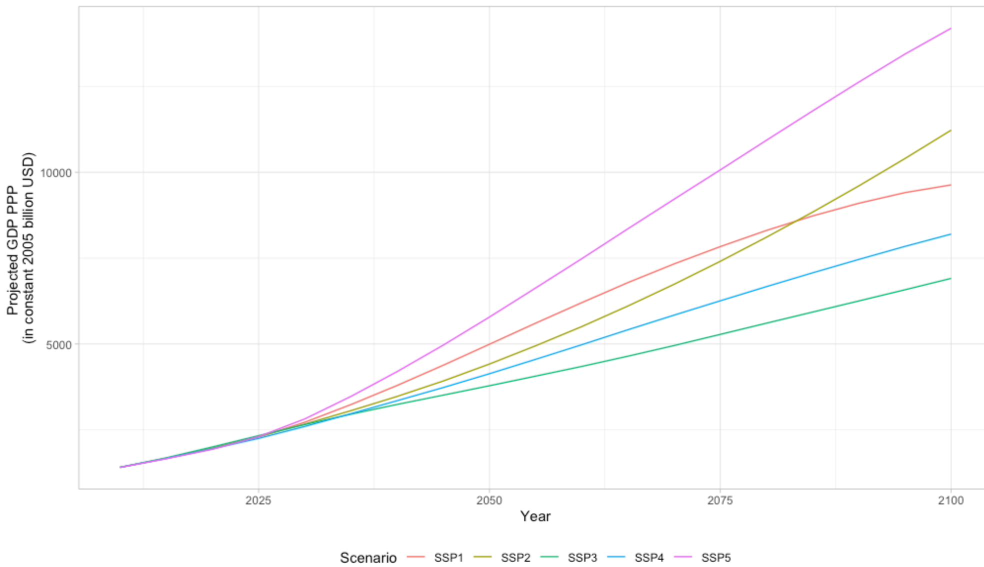
Table 1. Time periods when RCP8.5 reaches the global mean temperature thresholds in the different GCMs.

GCM	Baseline	1.5°C	2°C	3°C
CNRM-CM6-1	1985 - 2015	2018	2028	2045
CNRM-ESM2-1	1985 - 2015	2030	2041	2059
CanESM5	1985 - 2015	2028	2042	2062
EC-Earth3	1985 - 2015	2019	2032	2054
MIROC6	1985 - 2015	2033	2048	2071

Table 2. Time periods when RCP8.5 reaches the global mean temperature thresholds in the different GCMs.

Variable	Northwest	Northeast	Central-West	Central	Southeast
Mean Annual Temperature (°C)					
baseline	21.6°C	19.5°C	20.3°C	17.3°C	24.2°C
1.5°C	22.6°C	20.6°C	21.2°C	18.2°C	25.1°C
2.0°C	23.2°C	21.4°C	21.8°C	18.8°C	25.6°C
3.0°C	24.5°C	22.7°C	23.0°C	20.0°C	26.8°C
Annual Sum of Precipitation (mm)					
baseline	359.9	511.7	733.9	801.2	1491.5
1.5°C	373.1	518.5	754.6	812.4	1485.2
2.0°C	370.0	509.7	761.1	814.3	1489.6
3.0°C	358.7	490.5	733.1	800.7	1450.1

Figure 2. Below shows the GDP in purchasing power parity (GDP PPP) projections based on the different Shared Socioeconomic Pathways (SSP).



Note: GDP PPP projections under the different SSP scenarios.
Source: OECD.

3. RESULTS

3.1. Historical estimation of impacts

The panel regression shows that temperature significantly affects the gross value added (GVA) in all three sectors. Table 3 shows the regression results. The relationship is non-linear, following an inverted u-shaped functional form. This implies the existence of a production-maximizing temperature, with temperatures both below and above this optimum leading to a significant reduction in gross value added. This production-maximizing temperature is sector-specific: GVA in agriculture, industry, and services is maximized at 19.6°C, 22.9°C, and 22.3°C, respectively. A continued increase in temperatures beyond the production-maximizing temperature is estimated to unambiguously decrease the GVA.

Table 3. Regression results.

Dependent Variable (natural log)	Total GVA (1)	Agriculture (2)	Industry (3)	Services (4)
Temperature	0.643***	0.485***	0.401***	0.525***
	(0.140)	(0.103)	(0.103)	(0.095)
Temperature^2	-0.015***	-0.012***	-0.009***	-0.012***
	(0.003)	(0.002)	(0.002)	(0.002)
Precipitation	0.0002*	0.0005***	0.0002*	0.0001
	(0.0001)	(0.0001)	(0.0001)	(0.0001)
Precipitation^2	-0.00000	-0.00000***	-0.00000	-0.00000
	(0.00000)	(0.00000)	(0.00000)	(0.00000)
RX5		-0.001*		
		(0.001)		
SPI-1m moderately dry		0.026**		
		(0.010)		
SPI-3m severely dry		-0.039***		
		(0.011)		
SPI-6m extremely dry				-0.043*
				(0.025)
Time trend	0.024***	0.017***	0.019***	0.027***
	(0.001)	(0.001)	(0.001)	(0.0005)
Constant	7.820***	5.286***	8.811***	8.603***
	-1.414	-1.075	-1.067	(0.970)
Mesoregion FE	Yes	Yes	Yes	Yes
Mexican Peso Crisis 1995	Yes	Yes	Yes	Yes

Swine Flu 2009	Yes	Yes	Yes	Yes
Observations	185	185	185	185
R2	0.988	0.986	0.961	0.994
Adjusted R2	0.987	0.985	0.959	0.994
Residual Std. Error	0.058 (df = 173)	0.057 (df = 170)	0.100 (df = 173)	0.046 (df = 172)
F Statistic	1,276.250*** (df = 11;	840.311*** (df = 14; 170)	387.594*** (df = 11;	2,493.710*** (df = 12; 172)

Note: Statistical significance levels *p<0.1; **p<0.05; ***p<0.01. Dependent variables are the natural log of sectoral GVA.

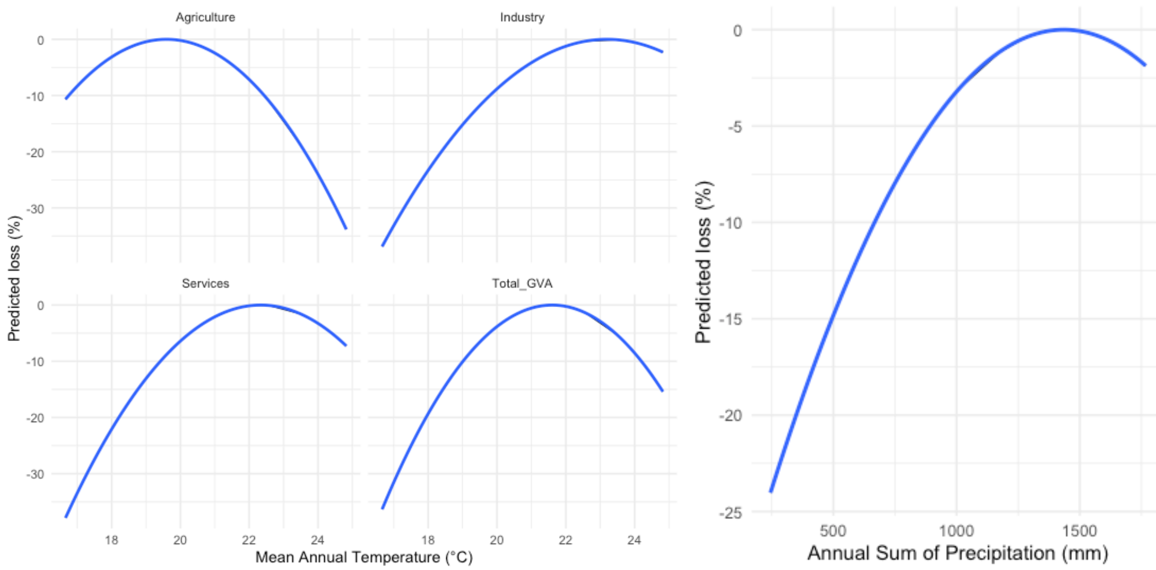
In terms of precipitation, only the agriculture sector shows a significant non-linear relationship, which suggests that too little or too much precipitation signifies suboptimal production. The estimated optimal annual sum of precipitation that maximizes agricultural output is 1435.3 mm. The industry sector on the other hand is positively and linearly benefiting from increases in precipitation. This might be linked to power generation and thus energy availability (e.g. hydropower[15] or cooling processes).

Variables controlling for extreme events show that heavy precipitation (RX5) and moderate drought calculated for a 3-month period reduces agricultural production, while one-month droughts do not show a negative impact[16]. Extreme events do not show any significant impacts on industry and services, except for extremely dry, 6-month drought time scale that shows a negative impact on services.

[15] As of 2017, 17 percent of the country's total installed capacity came from hydropower. This share is expected to increase further in the future (https://www.hydropower.org/country-profiles/mexico).

[16] Due to the short time scale of this indicator, it could be that the selection of crops can withstand minimal rainfall for a month, but not longer.

Figure 3. Estimated historical impacts from temperature (left) and precipitation (right) changes from years 1980-2016.



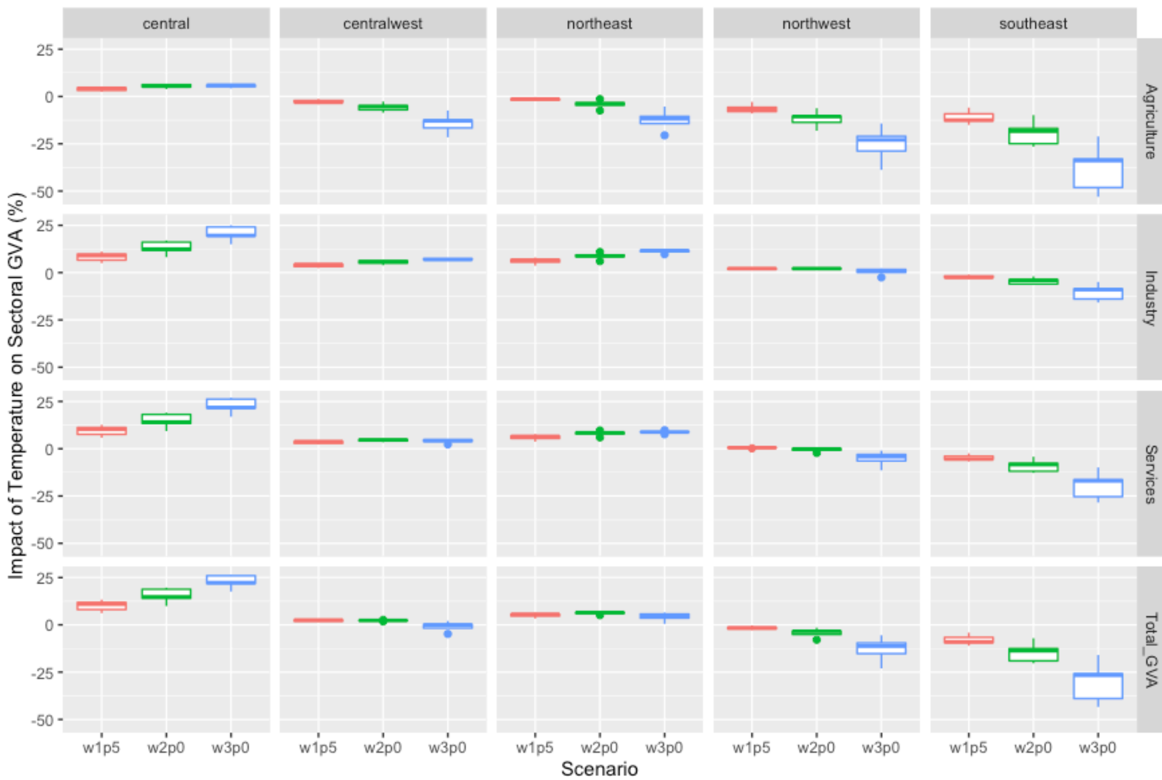
Note: Sectoral impacts were calculated by multiplying the coefficient of temperature and temperature squared, and precipitation and precipitation squared to the deviation of historical temperatures and precipitation in all mesoregions to estimated optimal. Note that based on the model, only the agriculture sector had significant impacts from changes in annual precipitation.

Plotting the actual historical temperature from 1980-2016 against estimated changes in the gross value added, Figure 3 shows that the agriculture sector has experienced losses as temperatures increase to more than 24°C, while industry and services have larger estimated losses as temperatures dropped to less than 18°C. On top of the impacts from temperature, the agriculture sector also shows significant losses with lower levels of precipitation for the same range of years, which has reached about 250 mm in a year.

3.2. Projected impacts on the mesoregion

3.2.1. Temperature impacts

Figure 4. Projected change in sectoral GVA due to temperature changes under different global warming scenarios compared to the baseline scenario.



Applying the impact estimates to future projections under different global warming scenarios, we see that some mesoregions gain with further warming, while others show losses. Regional differences in projected future impacts can largely be attributed to differences in the baseline temperature. Among the mesoregions, the Central region has the lowest temperature, which explains some gains as mean temperature increases. However, this is the reverse for the Southeast region as it is already experiencing temperatures above the estimated optimal. Figure 4 shows the changes in sectoral GVA in percent by mesoregion relative to the baseline scenario of no climate change. To capture uncertainties stemming from the different climate models used for the temperature projections, Figure 4 depicts the range of estimated impacts using boxplots. These represent the median estimate (inner bar), the 25th and 75th percentile estimate (lower and upper bound of the box) as well as the overall spread of the estimates (the end of the lower whisker equals the 25th percentile minus the difference between the 25th and the 75th percentile multiplied by 1.5; similarly, the end of the upper whisker is the 75th percentile plus 1.5 multiplied by this interquartile range) in one figure. The median estimate of projected changes in GVA by sector and mesoregion due temperature changes under the different warming scenarios relative to the baseline are presented in Table 4.

Table 4. Median estimates of projected changes by region in sectoral GVA due to temperature changes under different global warming scenarios (relative to baseline)

		Region				
Sector	**Scenario**	**Central**	**Central-West**	**Northeast**	**Northwest**	**Southeast**
Agriculture	w1p5	4.3%	-3.1%	-1.4%	-7.0%	-12.4%
	w2p0	5.5%	-5.4%	-3.8%	-10.6%	-18.4%
	w3p0	6.0%	-12.9%	-11.8%	-22.9%	-33.9%
Industry	w1p5	8.9%	3.9%	6.2%	1.4%	-3.3%
	w2p0	12.2%	5.1%	8.2%	1.3%	-5.2%
	w3p0	19.2%	5.7%	9.9%	-0.7%	-10.9%
Services	w1p5	10.3%	3.8%	6.5%	0.5%	-5.4%
	w2p0	14.1%	4.7%	8.4%	-0.1%	-8.4%
	w3p0	21.8%	4.3%	8.8%	-4.2%	-17.0%

3.2.2. Precipitation impacts

In terms of precipitation, the northeastern region is projected to experience reductions in the agricultural and total GVA under all warming scenarios relative to the baseline (median estimates). Losses increase with higher levels of warming (see Table 5). The Southeast on the other hand has the highest precipitation, and is estimated to experience minimal impacts in all scenarios. For the other regions, there are estimated small gains in a 1.5°C and 2°C scenarios compared to the baseline. Figure 5 shows the projected change in sectoral GVA in percent by mesoregion and warming scenario compared to a baseline of no climate change. Estimated impacts are again presented in the form of boxplots. For better readability, median estimates by sector, region and warming scenario are shown in Table 5.

Figure 5. Projected change in agricultural and total GVA due to precipitation changes under different global warming scenarios compared to the baseline scenario.

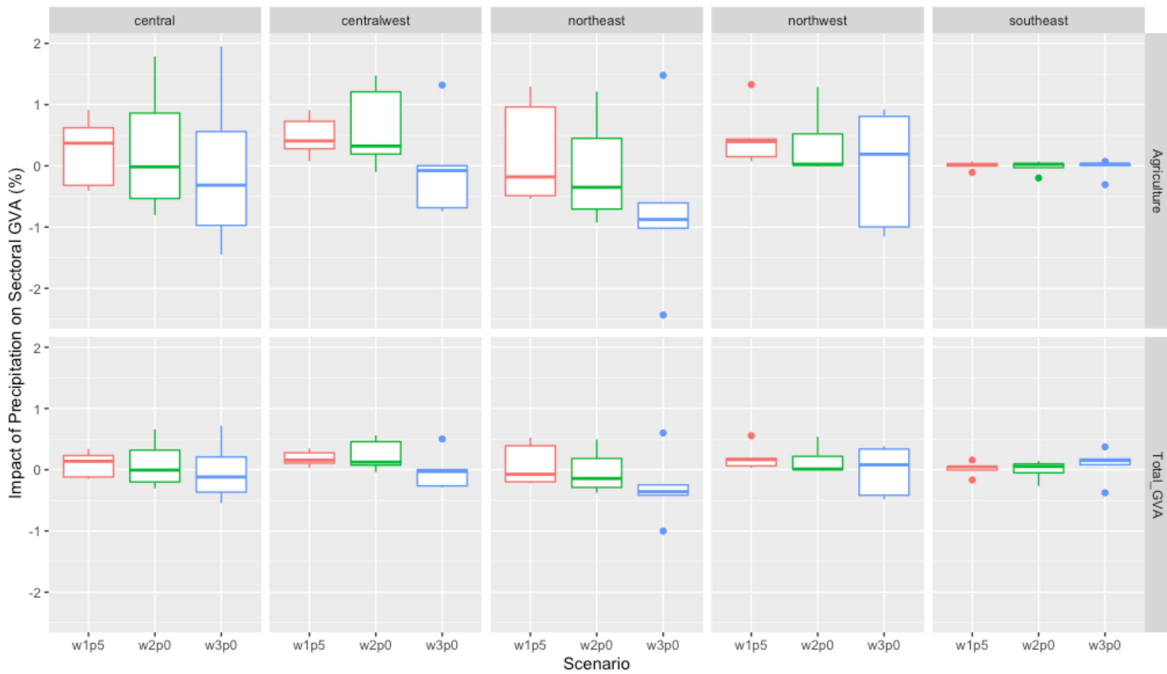


Table 5. Median estimates of projected changes by region in sectoral GVA due to precipitation changes under different global warming scenarios (relative to baseline)

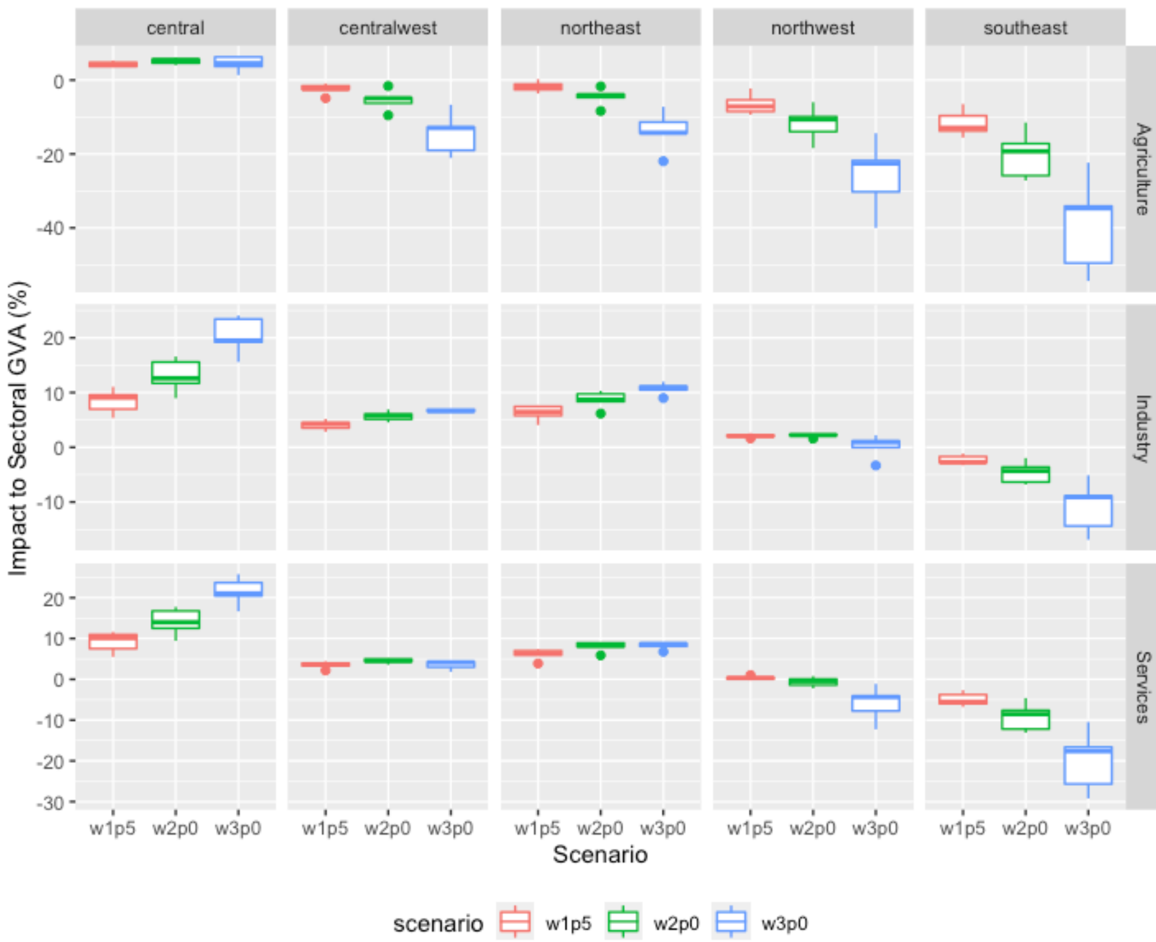
		Region				
Sector	Scenario	Central	Central-West	Northeast	Northwest	Southeast
Agriculture	w1p5	0,37%	0,41%	-0,18%	0,40%	0,02%
	w2p0	-0,02%	0,32%	-0,35%	0,03%	0,03%
	w3p0	-0,31%	-0,08%	-0,88%	0,19%	0,03%
Total GVA	w1p5	0,14%	0,16%	-0,07%	0,17%	0,05%
	w2p0	-0,01%	0,12%	-0,14%	0,01%	0,05%
	w3p0	-0,12%	-0,03%	-0,36%	0,08%	0,15%

3.2.3. Combined effects

Looking at the combined impacts of climate changes on the sectors in different mesoregions (Figure 6), we see that the northwest and southeast regions are estimated to have the largest losses due to global warming. Impacts are projected to get worse with higher levels of global warming. Furthermore, projected losses in these regions are highest in the agricultural sector, followed by the services and then the industry sector.

The central region gains in all sectors with higher benefits from warming, while central-west and northeast regions would slightly benefit from warming only for industry and services sectors, but would incur losses in the agriculture sector.

Figure 6. Sectoral impacts of climate change relative to the baseline period, 1985-2015. The impacts are due to a combination of future changes in temperature, precipitation, extreme precipitation (RX5), and drought (SPI).



3.3. Comparison to other reports

This study complements existing publications [17] on projected future climate change impacts in Mexico in several ways. First, it expands the list of sectors considered to complete the production side of the economy. While the 6th National Communication to the UNFCCC [5] focused on the agriculture, health, energy and tourism sector, the present study also includes analyses of the industry and services sector. Second, this report is based on the latest available data and also considers extreme events in the analysis, in addition to

[17] The Economics of Climate Change in Mexico [7], and the 6th National Communication to the UNFCCC [5].

investigating overall trends in temperature and precipitation. Furthermore, the present study gives importance to sectoral shares and development plans as large factors in determining the magnitude of climate change impact, historically and in the future.

To put results of the different publications into perspective, it is worth noting the differences in the methodological approaches taken. First, the present report conducts econometric analyses of the sectoral GVA in response to projected temperature and precipitation changes. The 6th National Communication to the UNFCCC [5] estimates economic costs of different mitigation pathways based on the Integrated Assessment Model CLIMRISK-RIVER[18]. Also, time periods used in the estimation of historic impacts differ between reports (1940-2013 vs. 1980-2016). Furthermore, economic impacts in the present report are calculated for different levels of global warming (1.5°C, 2°C and 3°C), while other publications base their analysis directly on different RCPs (RCP4.5 in particular). Finally, monetary estimates of future economic impacts might depend on the discount rate assumed in the projections. The present report therefore focuses on relative changes in economic activity.

Overall, while exact projected economic damages in the different reports are hard to compare due to the mentioned methodological differences, general trends and conclusions are very similar. In particular, both reports find important losses in the agriculture sector, as many crops will be less suitable for production in Mexico by 2030 already [5]. Also, the regional spread of projected impacts matches closely, with larger losses projected for coastal areas (6th National Communication [5]) and the northwest and southeastern region (the present report) as well as potential gains in the central region found in both reports.

Finally, the present report also complements the Climate Vulnerability Assessment (CVA) for Mexico that is currently being prepared under the GCF technical advisory services. Methodological differences between the two reports – for example, the CVA focuses on the number of people affected by a particular climate indicator as opposed to economic damages analyzed in this report – again do not allow for a direct integration of results, but vulnerability trends for relevant indicators match.[19] As such, while the central region seems again least impacted by the climate stress indicators analyzed in the CVA, particularly the Western regions (northwest and central-west) are projected to have a large share of their population affected by many climate risks. This aligns well with the regional climate impact patterns found in this report. Furthermore, most climatic

[18] See https://www.sciencedirect.com/science/article/pii/S1364815219308369 for a description of the model.

[19] Some structural similarities between the two assessments exist however. As such, both draw on the same five climate models from the ISIMIP project, have a 0.5° grid resolution (aggregated to the state level for the macroeconomic analysis) and are assessed at 1.5, 2.0 and 3.0°C.

stresses are likely to affect a larger number of people under higher levels of global warming. Finally, in line with the relatively large projected impacts in the agricultural sector presented in this report, heat and water stress appear to be the most relevant stresses in the CVA as well.

4. CONCLUSIONS

This macroeconomic risk profile presents the estimated changes in climate due to global warming. Global warming levels are influenced by the amount of mitigation action done globally – not just Mexico – and, therefore, present uncertainty in its accomplishment. In this regard, we present in this analysis scenarios in which the NDC commitments are met globally (~3°C global warming relative to preindustrial times – see e.g. UNEP 2020) [18]), as well as more ambitious climate action: a 1.5°C Paris Agreement-consistent scenario, and a 2°C scenario. following the Paris Agreement (1.5°C and 2°C global warming scenarios relative to preindustrial times). We relate the global warming levels to Mexico-specific climate projections, in order to estimate the economic impacts in the future. As shown in Table 1, the magnitude of change in temperature and precipitation also differs by mesoregion under each scenario.

The results of the analysis show that global warming at different levels have sector- and mesoregion-specific impacts. The agriculture sector will have the largest losses as temperatures increase across all regions (with the exception of the central region). Losses in the agriculture sector do not only come from increased surface temperatures, but also the possibility of lower amounts of precipitation. Based on the climate projections, the trend in changes in future precipitation is not as prominent as temperature changes, and therefore show minimal impacts. Climate change impacts for the industry and services sector are mixed. The gross value added in the industry and services sector is projected to decline in the northwest and southeast regions with higher levels of global warming, while the GVA in both sectors is projected to increase slightly in the other regions.

Overall, projected future climate change impacts depend on present-day differences in climates in the mesoregions. In particular, regions that are already experiencing warm climates above or around the production-optimizing temperature, such as southeast and northwest, are estimated to experience large losses in all sectors as warming continues. The central region on the other hand is expected to see some economic gains in further warming, leading up to the production-optimizing temperature.

Put together, future national economic impacts due to climate change are likely to be influenced by the sectoral as well as regional composition of the economy.

Historically, contributions of the agricultural sector to the total GVA have been small (around 2.5 percent on average). The projected climate-induced losses in the agricultural sector will thus have only limited impacts on the overall economic activity if the sectoral composition remains constant. However, the mesoregions projected to experience the highest economic losses (northwest and southeast region) have so far contributed on average more than a third to national GVA. This will have important repercussions on the overall economic activity.

The results of this analysis hopefully aid policy decisions in prioritizing adaptation in climate-vulnerable sectors, allocation of investments, and serve as a guiding document for planned economic structural changes in order to minimize climate change impacts, alongside strong mitigation action. As the economic vulnerability assessments have shown, adaptation efforts should focus in particular on the agricultural sector as well as on the Southeast and Northwestern region given their projected vulnerability to changing temperature and precipitation patterns.

5. ANNEX

The script for the model code programmed in the open-source software R has been provided to INECC and the NDA. It includes a more detailed description of the underlying steps and data processing.

Table 6. Historical economic data from INEGI

Variable	Northwest	Northeast	Central-West	Central	Southeast
Gross value-added, Total, mean 1980-2016, constant 2013 million Mexican Peso	1,624,885	3,065,217	3,154,355	3,549,266	3,786,800
Gross value-added, Agriculture, Forestry, and Fisheries, mean 1980-2016, constant 2013 million Mexican Peso	68,657.24	67,854.28	124,342.3	38,409.79	112,041.6
Gross value-added, Industry, mean 1980-2016, constant 2013 million Mexican Peso	408,662.2	785,087.8	621,060.1	826,133	1,520,720

Gross value-added, Services, mean 1980-2016, constant 2013 million Mexican Peso	574,195.7	1,040,643	1,222,860	2,684,723	1,352,838

Table 7. Historical climate data from GSWP3-W5E5.

Variable	North-west	North-east	Central-West	Central	South-east
Mean Annual Temperature (°C), mean over the period 1980-2016	21.5	19.4	20.2	17.2	24.1
Annual Sum of Precipitation (mm), mean over the period 1980-2016	365.2	514.7	747.3	814.7	1494.2
RX5 (mm), mean 1980-2016	44.6	44.5	48.9	38.5	74.1
Consecutive Dry Days (CDD), number of events in a calendar year**, mean 1980-2016	10.3	14.0	11.2	12.2	13.2
SPI-1 month, total number of moderately dry months*, 1980-2016	0	5	5	18	6
SPI-1 month, total number of severely dry months*, 1980-2016	0	0	0	1	0
SPI-1 month, total number of extremely dry months* , 1980-2016	0	0	0	1	0
SPI-3 month, total number of moderately dry months*, 1980-2016	7	20	19	21	6
SPI-3 month, total number of severely dry months*, 1980-2016	3	3	1	9	3
SPI-3 month, total number of extremely dry months*, 1980-2016	0	0	1	2	0
SPI-6 month, total number of moderately dry months*, 1980-2016	19	18	16	26	9
SPI-6 month, total number of severely dry months*, 1980-2016	4	5	3	9	1

SPI-6 month, total number of extremely dry months*, 1980-2016	0	0	1	3	0

Note: * Moderately dry months: SPI<-1.0, severely dry months: SPI<-1.5, extremely dry months: SPI<-2.0. Calculation of SPI sourced from McKee et al., 1993 [4]. For an explanation on the interpretation of the SPI see also WMO (2012) [19]. ** CDD events are consecutive 5-day minimum that rainfall was less than 1mm.

6. REFERENCES

[1] World Bank Country Overview: Mexico. Updated on October 9, 2020. URL: https://www.worldbank.org/en/country/mexico/overview

[2] IMF Article IV Mission Concluding Statements. October 6, 2020. URL: https://www.imf.org/en/News/Articles/2020/10/06/mcs100620-mexico-imf-staff-concluding-statement-of-the-2020-article-iv-mission

[3] USAID Climate Risk Profile: Mexico. May 2017. URL: https://www.climatelinks.org/sites/default/files/asset/document/2017_USAID_Climate%20Change%20Risk%20Profile_Mexico.pdf

[4] McKee, T.B., Doesken, N.J., Kleist, J, (1993). The relationship of drought frequency and duration to time scales. In: Preprints, Eighth Conference on Applied Climatology, January 17 e 22, Anaheim, California, pp. 179 e 184.

[5] SEMARNAT and INECC (2018). Sexta Comunicación Nacional y Segundo Informe Bienal de Actualización ante la Convención Marco de las Naciones Unidas sobre el Cambio Climático Nacional. URL: http://cambioclimatico.gob.mx:8080/xmlui/handle/publicaciones/117

[6] SEMARNAT-INECC (2016). Mexico's Climate Change Mid-Century Strategy. Ministry of Environment and Natural Resources (SEMARNAT) and National Institute of Ecology and Climate Change (INECC), Mexico City, Mexico.

[7] SEMARNAT-INECC (2009). The Economics of Climate Change in Mexico. Ministry of Environment and Natural Resources (SEMARNAT) and National Institute of Ecology and Climate Change (INECC), Mexico City, Mexico. URL: https://biblioteca.semarnat.gob.mx/janium/Documentos/Cecadesu/Libros/Economics%20of%20climate%20change.pdf

[8] Climate Indices. https://www.climdex.org.

[9] NCAR UCAR. Climate Data Guide. https://climatedataguide.ucar.edu/climate-data/standardized-precipitation-index-spi

[10] Schleussner, C. F. , Lissner, T. K., Fischer, E. M., Wohland, J. , Perrette, M., Golly, A., Rogelj, J., Childers, K., Schewe, J., Frieler, K., Mengel, M., Hare, W., and Schaeffer, M. (2016). Differential climate impacts for policy-relevant limits to global warming: the case of 1.5°C and 2°C. Earth System Dynamics 7, 327–351, doi:10.5194/esd-7-327-2016

[11] Katrina Jessoe & Dale T. Manning & J. Edward Taylor (2018). "Climate Change and Labour Allocation in Rural Mexico: Evidence from Annual Fluctuations in Weather," Economic Journal, Royal Economic Society, vol. 128(608), pages 230-261, February.

[12] Kjellstrom, T., Otto, M., Lemke, B., Hyatt, O., Briggs, D., Freyberg, C., & Lines, L. (2016). Climate Change and Labour: Impacts of Heat in the Workplace. Retrieved from http://www.undp.org/content/undp/en/home/librarypage/climate-and-disaster-resilience-/tackling-challenges-of-climate-change-and-workplace-heat-for-dev.html

[13] Park, J. (2015). Will We Adapt? Temperature Shocks, Labor Productivity, and Adaptation to Climate Change in the United States (1986-2012).

[14] Parsons, K. C. (2014). Human Thermal Environment. The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort, and Performance (3rd editio). https://doi.org/10.4324/9780203302620

[15] Huang, C., Barnett, A. G., Wang, X., Vaneckova, P., FitzGerald, G., & Tong, S. (2011). Projecting future heat-related mortality under climate change scenarios: a systematic review. Environmental health perspectives, 119(12), 1681-1690.

[16] van Vuuren, D.P., Edmonds, J., Kainuma, M. et al. The Representative Concentration Pathways: An Overview. Climatic Change 109, 5 (2011). https://doi.org/10.1007/s10584-011-0148-z

[17] Government of Mexico, Ministry of Environment and Natural Resources (2020) Nationally Determined Contributions. 2020 Update. https://www4.unfccc.int/sites/ndcstaging/PublishedDocuments/Mexico%20First/NDC-Eng-Dec30.pdf page 22

[18] UNEP (2020) Emission Gap Report 2020. United Nations Environment Programme. https://www.unep.org/emissions-gap-report-2020

[19] WMO (2020). Standardized Precipitation Index User Guide. World Meteorological Organization.
https://library.wmo.int/index.php?lvl=notice_display&id=13682#.YEq3EmMo9ZK