Vulnerability to climate change: An analysis of its conceptualization in Mexico

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Abstract:

The concept of climate change vulnerability (CCV) has become an angular one for understanding the differential impacts of climate change (CC). It has evolved from multiple disciplines, leading to a diversity of conceptual frameworks. Particularly, in Mexico – where CCV research and practice have increased – such diversity has resulted in a lack of clarity on how to operationalize it, and limited replicability. In this context, this research aims to identify how CCV is conceptualized in Mexican policies and by practitioners, and to analyze if the socioecosystem perspective contributes to its integral comprehension and facilitates its operationalization. To do so, we developed: a) a content analysis of 27 CC Mexican policies; and b) interviews applied to 15 practitioners. Results show that two main conceptualizations of CCV are dominant: outcome vulnerability and contextual vulnerability, each being represented by an Intergovernmental Panel on Climate Change (IPCC) framework, the Fourth and the Fifth Assessment Reports (AR4 and AR5 respectively). Policies and interviewees present inconsistencies in the stated conceptual framework, definition, and components of CCV, which shows a limited understanding of the concept. Regarding the socioecosystem perspective, 44% of the policies adopt it, while only one practitioner incorporates the perspective into practice. We conclude that CCV global frameworks are not properly adopted in Mexico due to limited guidance for applying the theory into practice. Also, the existing frameworks do not reflect the complexity of CCV, and therefore, the use of socioecosystem approaches may lead to a better understanding.

Key policy insights:

- Policies entitled to evaluate CCV should provide not just a definition for vulnerability and its components, but also guidance to operationalize the specific conceptual framework to the approach under which they are created.
- The development of national data and indicators bases is fundamental to being able to analyze CCV under a socioecosystem perspective, as well as to promote replicability and M&E of policies.
- The adoption of socioecosystem approach for analyzing climate change vulnerability facilitates the operationalization of the most used conceptual frameworks in Mexico: IPCC AR4 and AR5.

Key words: Climate change vulnerability; conceptualization; contextual vulnerability; outcome vulnerability; socioecosystem approach; public policy; operationalization.

I. Introduction

Climate change (CC) is recognized as one of the biggest threats to life and human well-being, and one of the most challenging problems for the present and the future (IPCC et al., 2022; K. L. O'Brien & Leichenko, 2000; Schipper et al., 2020). Its impacts, generally having negative consequences (Mora et al., 2018), are already perceived all around the world (Asmus et al., 2019; Chen et al., 2011; IPCC, 2014b, 2019, 2021; McCarty, 2001; Talloni-Álvarez et al., 2019). Since it poses considerable social, economic, and environmental risks, in the last decades political awareness has increased, as well as mobilization towards adaptation to CC (Gupta, 2010).

CC impacts are different at local, regional, and global scales (Adger, 2006; Forbes et al., 2004; Murray-Tortarolo, 2021), and between social sectors and livelihoods (Blaikie et al., 2005; IPCC, 2014b).

Under this context, the concept of ***climate change vulnerability (CCV)*** has become an angular one through which the differential impacts of CC (potential and actual) can be understood. The broad idea behind the concept of vulnerability is *susceptibility to be damaged or harmed, to be powerless and marginal* (Adger, 2006; Eakin & Luers, 2006). Vulnerability has been used by a variety of disciplines, based on specific ontological conceptualizations, and using different epistemological ways to study it (Moret, 2014; Nightingale, 2016; Soares et al., 2012). Specifically, in CC research, which requires scholars of multiple fields to work together to be able to understand both, complex biophysical and social processes, the concept has been adopted from multiple disciplines, leading to different conceptualizations -defined as a description of an abstract phenomena (Leshem & Trafford, 2007), and methodologies (Nightingale, 2016). The use of one specific conceptual framework leads to specific normative conclusions and ways to address it (Eakin & Luers, 2006). Therefore, policymakers, scholars, and practitioners need to be aware of the conceptual framework where it is rooted (K. O'Brien, 2006).

Referring to its conceptualization, there are two predominant trends. One conceives CCV to be determined by biophysical factors that depend on the hazard characteristics (i.e., type, location, magnitude) and the potential negative effects on the system (influenced by precarious physical environments or degraded environments) (Eakin & Luers, 2006; Füssel, 2007; K. O'Brien, Eriksen, et al., 2004; Soares et al., 2012). In this case, CCV is conceptualized as an outcome that results from the potential impacts that can no longer be reduced, or as the degree of the damage caused (Adger, 2006; Eakin & Luers, 2006; Füssel, 2007; Nguyen et al., 2016; Soares et al., 2012). The other trend states that CCV is determined by a multidimensional space of sociopolitical, cultural, and economic factors of a macro-structure, that defines differential exposure to hazards, impacts, and capacities to cope, adapt, or recover from such hazards at a local scale (Bohle et al., 1994; Eakin & Luers, 2006; Smit & Wandel, 2006). It is an inherent property of a system, independent from hazards, socially constructed from historic and dynamic processes (Eakin & Luers, 2006; K. O'Brien, Eriksen, et al., 2004; Soares et al., 2012). Under this argument, CCV is said

to be contextual or starting-point vulnerability (Dasgupta et al., 2014; Nguyen et al., 2016). However, more integrated conceptual frameworks are needed for linking hazards and historical conditions. Since socioecosystems approaches are integrated ones (Maass, 2018), applying this approach is thought to help to understand vulnerability not only to global change but also to different types of stresses and hazards (Eakin & Luers, 2006).

Moreover, since Climate Change Sciences require consensus, the Intergovernmental Panel on Climate Change (IPCC), a United Nations body for assessing the related science, has become an authority on the matter (Adger, 2006; IPCC, 2020). The IPCC has developed conceptual frameworks considering multi-dimensional issues (Das et al., 2020), which have been adopted by most parties of the United Nations Framework Convention on Climate Change. Particularly, the Fourth and the Fifth Assessments Reports (AR4 and AR5, respectively) are the ones most adopted around the world (Estoque et al., 2023).

Mexico is one of the most vulnerable countries to CC, mainly because of geographical conditions and the influence of global factors on its climate (Murray-Tortarolo, 2021). Social, economic, and political conditions are also responsible for such vulnerability, such as poverty and marginalization; productive activities and livelihoods; access credits and insurances; and technical, civil protection, and planning capacities (Conde & Gómez, 2014), among others. Because of its condition, CCV research in Mexico has been increasing since 2007, focusing on multiple study subjects: biological, socioeconomic, territories, and natural resources. Additionally, a diversity of conceptual frameworks, methods, and indicators have been employed (Nájera-González & Carrillo-González, 2022). The latter limits the capacity to assess progress in the matter and even contributes to biases that can affect decision-making processes (Mac Gregor-Gaona et al., 2021) and the development of policies.

The diversity of ways of conceptualizing CCV, or conceptual frameworks, has led to a lack of clarity, ambiguity, and even contradiction between concepts (Klopfer et al., 2021; Lauerburg et al., 2020). It is also difficult to obtain directions to study CCV and to identify proper methods; for which some authors have

called for an effort to unify CC research in the matter, as well as identifying the methodological challenges to do so (Klopfer et al., 2021). For that reason, this research aims to identify how CCV is conceptualized in Mexican policies and by practitioners; to describe if the socioecosystem perspective has permeated CCV practice; and to identify enablers and constraints for the operationalization of CCV.

II. Methods

To achieve these objectives, the following methods were used: a) a content analysis of CC policies in Mexico and their relation to the existing conceptual frameworks; b) an analysis of how practitioners conceptualize and operationalize CCV. Detailed explanations are provided for both parts in the following sections:

a) Content analysis of Mexican Climate Change Policies

Several public policies relevant to Mexico were analyzed using specific criteria related to their implementation and relationship with CC plans and programs. The General Law of Climate Change (known as LGCC, in Spanish) (DOF, 2012a) is the policy that establishes the legal framework for all other policies, plans, programs, and strategies entitled to boost adaptation, and states responsibilities within governmental institutions and sectors on the matter (Ávila Akerberg, 2012). Therefore, it was used as the entry point for identifying a) specific CC policies; and b) sectors that may contribute to the development and implementation of CC policies.

The LGCC cited a total of nine policies, which are categorized as planning policies; regulatory policies; or policies that provide information for decision-making processes (data policies) (INECC, 2019b). Of those, five were considered for this analysis due to their availability and relevance to CCV. The LGCC also states five sectors as contributors and implementers of climatic policies (see Table 2). Therefore, policies regarding CCV and adaptation of those sectors were identified and analyzed. Other policies suggested by practitioners during interviews (see following section), were also considered (Table 2).

136 The total number of analyzed public policies was 27, and the analysis was conducted using the
137 software Atlas.ti (version 8). The categories used for the analysis were related to the definition and
138 conceptual framework of CCV used; other relevant concepts that could provide information about the
139 conceptual framework behind it, and its way to operationalize it; the socioecosystem perspective. In this
140 last regard, the analysis includes a qualitative classification of the degree of adoption of some
141 socioecosystems' attributes proposed by (Challenger et al., 2014) and (Challenger, Cordova, et al., 2018),
142 and quantification of some concepts or ideas, as described in Table 1.

143

144 *Table 1. Analyzed socioecosystems attributes in Mexican climate change public policies, based on* (Challenger, Córdova, et al.,
145 2018; Challenger et al., 2014)*. The table includes a description of how the attributes are adopted, as well as the occurrences of*
146 *specific concepts or ideas.*

Attribute	Categories of adoption			Quantification
	Not included	Moderately included	Widely included	
Ecosystem approach	Not included.	Traditional ecosystem perspective: societies benefit from ecosystems.	Nature and society are interdependent; comprise a complex system.	References to the relation between ecosystems – nature.
Integrated basin approach	Not included.	Considers watersheds as a territorial management criterion.	Considers integrated basin approach, and participation of multiple stakeholders.	Times the concept "basin" appears in text.
Interdisciplinary approach	Not included.	Promotes use of scientific, technical, and technological knowledge.	Promotes exchanges and use of different types of knowledge, including traditional and local knowledge.	-
Environmental streaming	Not included.	Calls for collaboration among sectors.	Explains the different sectors and levels in which	References to environmental streaming.

			collaboration, coordination and alliances may occur, as well as mechanisms to fulfill it.	
Public/private financing	Not included.	States the need to develop financial mechanisms that include society.	States multiple stakeholders and sectors that should take part in financing.	-
Participation	Not included.	States participation of different public institutions.	States participation of multiple sectors and stakeholders.	-
Sustainability	Not included.	Uses the concept.	Reflects and understanding of sustainability including social, ecological and economic spheres.	Times the concepts "sustainability" or "sustainable" appear in text (includes two translations for Spanish: *sustentable*; sustentabilidad; sostenible; sostenibilidad)
Long-term vision	Not included or considers a short-term vision.	Refers to a middle-term temporality.	Developed for a long-term temporality.	-
Monitoring and evaluation	Not included.	Emphasizes the importance of M&E.	Includes a temporality or guidance for M&E.	-
Adaptive Management	Not included.	-	Refers to flexibility and adaptability of the public policy according to the context, learning processes, and adaptive management.	-

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b) Conceptualization and operationalization of CCV by Mexican practitioners

A semi-structured interview was designed and applied to eight key practitioners from governmental and non-governmental institutions, who have been involved in the development and implementation of CCV policies. Seven more key practitioners were identified during these interviews, through the snowball sample method (Naderifar et al., 2017), who were also interviewed. A total of 15 practitioners were interviewed from March to April 2021. After being transcribed, the analysis of the interviews was conducted using the software Atlas.ti (version 8). The main predetermined categories were the definitions and conceptual framework that each practitioner uses; ideas and expressions that reflect how CCV is conceptualized; the objectives for developing CCV assessments (quantifying the number of times that a specific objective was mentioned by any practitioner); the purposes for which the concept of CCV has been useful; the enables and constraints that interviewees identify for operationalizing the concept; any conceptual framework that practitioners identify to have contributed to CCV study. Finally, the adoption of the socioecosystem perspective in practice was analyzed, based on unit of study (basin or not basin); and weighting of the natural and social elements contributing to CCV.

III. Results

CCV frameworks in Mexican policies

The definitions of CCV reflect the conceptual framework from which they derive, and how it must be operationalized. The first highlight in this regard is that 70% of the analyzed public policies (n=27) stated a CCV definition. Of the rest, 7% do not need to include it because they are not directly related to CC (ENBioMEX, PSADER). However, 22% of the policies focus on CCV and do not state a definition (NDC, PCC-ENT, REG-LCC-DF, ELAC-PAC-CDMX, ERCDMX) (Table 2).

173 *Table 2. Analyzed public policies based on policies and sectors stated in the General Law of Climate Change of Mexico* (DOF, 2012a).

174 *Acronyms correspond to their name in Spanish. *R stands for Regulatory policies; P: Planning policies; D: Data policies.*

Sector (According to LGCC)	Public policy	Acronym	Year of revised publication	Reference	Type*	Scale
Policies stated in LGCC	General Law of Climate Change	**LGCC**	2020	(DOF, 2012a)	R	National
	National Strategy of Climate Change Vision 10-20-40	**ENCC**	2013	(ENCC, 2013)	P	National
	Climate Change Special Program 2014-2018	**PECC**	2014	(SEMARNAT, 2014)	P	National
	National Determined Contributions to the Paris Agreement	**NDC**	2020	(Gobierno de México & SEMARNAT, 2020)	P	National
	National Strategy for Biodiversity	**ENBioMEX**	2016	(CONABIO, 2016)	P	National
	Subprogram for Biodiversity Protection and Sustainable Management against Climate Change			-	P	National
National Climate Change Policy	Guidelines for the elaboration of Climate Change Programs for States	**PCC-ENT**	2015	(SEMARNAT & INECC, 2015)	R	State
	Mexico City's Law for climate change mitigation and adaptation, and sustainable development	**LCC-CDMX**	2017	(México, 2011)	R	State
	Rules for Mexico City's Law for climate change mitigation and adaptation, and sustainable development	**REG-LCC-DF**	2012	(Gaceta Oficial del Distrito Federal, 2012)	R	State
	Law for climate change action for Jalisco	**LACC-JAL**	2015	(Congreso de Jalisco, 2015)	R	State
	Mexico City's Local Strategy for Climatic Action 2021-2050 and Program for Climate Action 2021-2030	**ELAC-PAC-CDMX**	2021	(SEDEMA, 2021)	P	State
	Jalisco State's Program for Climate Action	**PEACC**	2018	(SEMADET, 2018)	P	State
	Jalisco State's Climate Change Adaptation Plan	**PLAN-JAL**	2019	(Muñoz Alarcón et al., 2019)	P	State
	Mexico City's Resilience Strategy	**ERCDMX**	2016	(SEDEMA, 2018)	P	State
	Program for Climate Action for Álvaro Obregón Municipality	**PAC-AO**	2018	(Gaceta Oficial de la Ciudad de México, 2018a)	P	Municipal
	Program for Climate Action for Xochimilco Municipality	**PAC-XOCH**	2018	(Gaceta Oficial de la Ciudad de México, 2018b)	P	Municipal
Integrated risk management	National Atlas for Climate Change Vulnerability	**ANVCC**	2019	(INECC, 2019a)	D	National / State / Municipal
	General Law for Civil Protection	**LGPC**	2020	(DOF, 2012b)	R	National
	Guidelines for the elaboration of National Risk Atlas	**G-ANR**	2016	(DOF, 2016)	R	National
	Guidelines for elaboration of State and Municipal Atlas of Hazards and Risks	**ATLAS-PR**	2014	(CENAPRED & SEGOB, 2015)	D / R	State / Municipal
	Mexico's vulnerability to climate change. A review of Civil Protection National System	**VUL-MEX**	2018	(Zepeda Gil et al., 2018)	D	National
Water resources	Guidelines for the elaboration of flood risk maps	**LEMPI**	2014	(CONAGUA, 2014)	R	National
	National Water Program 2020-2024	**PNH**	2020	(CONAGUA, 2020)	P	National
Agriculture, livestock, forestry, fisheries, and aquaculture	Agriculture and Livestock Program 2019-2024	**PSADER**	2019	(SADER, 2021)	P	National
Biodiversity and ecosystems	Climate Change Strategy for Protected Areas	**ECCAP**	2015	(CONANP, 2015)	P	National
	Rapid Assessment Tool for Climate Change Vulnerability of Protected Areas	**DRV**	2015	(CONANP & CEGAM-Slim, 2015)	D	National
	Guidelines for elaboration of Protected Areas' Climate Change Programs	**PACC-ANP**	2020	(CONANP-PNUD, 2021)	D / R	National
	Mexico's REDD+ National Strategy 2017-2030	**ENAREDD+**	2017	(CONAFOR, 2017)	P / R / D	National

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Although LGCC should be the legal framework for all CC public policies, from the 19 policies that define CCV only 53% use the one that it states, which corresponds to IPCC AR4 definition: "degree to which a system is susceptible to, and unable to cope with, adverse effects of CC, including climate variability and extremes" (IPCC, 2014b). 26% of policies use the IPCC AR5 definition: "propensity or predisposition to be adversely affected" (IPCC, 2014a); 5% state both IPCC definitions (AR4 and AR5); and 16% state definitions related to risk theory: two of them refer to "incapability to anticipate, prevent, cope, resist and recover from a stressor/disaster"; while one distinguishes between physical vulnerability (susceptibility or propensity of an exposed system to suffer harm) and social vulnerability (capacity of societies to avoid harm and to recover from the impacts of a stressor) (Table 3). Some policies even state the conceptual framework on which they are based, which are the ones proposed by the IPCC (AR4 and AR5) (Figure 3). However, it is noteworthy that some policies have inconsistencies: they define CCV under AR4 or AR5 but claim to be based on the other IPCC's conceptual framework or use the other's components, being the case of ENCC, PACC-XOCH, ECAPP (Table 3).

Table 3. Components of vulnerability and related concepts according to different Mexican public policies. N/S refers to not specified.

Public policy	Provided definition	Conceptual framework	Components of CCV	CCV concept linked to resilience concept
LGCC	IPCC, 2007	N/S	Exposure, sensitivity, adaptive capacity	Yes
ANVCC	IPCC, 2007**	AR4		Yes
PCC-ENT	N/S	AR4		No
PLAN-JAL	IPCC, 2007	N/S		Yes
PACC-ANP	IPCC, 2007	AR4		Yes
PEACC	IPCC, 2007	N/S		Yes
PAC-AO	IPCC, 2007	N/S		No
PAC-XOCH	IPCC, 2014	AR4		Yes
ENCC	IPCC, 2007	AR5	Sensitivity, adaptive capacity	Yes
ECCAP	IPCC, 2007	AR5		Yes
DRV	IPCC, 2014	AR5		Yes
LEMPI	N/S	AR5		No
G-ANR	Risk theory	N/S	Physical vulnerability: intensity, stressor; Social vulnerability: economic, social, and cultural factors	No
PECC	IPCC, 2007	N/S	Exposure, capacity of response, social and institutional capacities	No
ELAC-PAC-CDMX	N/S	N/S	Sensibility to economic impacts	Yes
ERCDMX	N/S	N/S	Response capacity; adaptive capacity; poverty, gender bias, marginality	Yes
VUL-MEX	IPCC, 2014	N/S	N/S	Yes
PNH	IPCC, 2014	N/S	N/S	Yes
LGPC	IPCC, 2014	N/S	N/S	Yes
LCC-CDMX	IPCC, 2007	N/S	N/S	No
ENAREDD+	IPCC, 2007	N/S	N/S	Yes
LACC-JAL	Risk theory	N/S	N/S	Yes
ATLAS-PR	Risk theory	N/S	N/S	No
PSADER	N/S	N/S	N/S	Yes
REG-LCC-DF	N/S	N/S	N/S	No
NDC	N/S	N/S	N/S	Yes
ENBioMEX	N/S	N/S	N/S	Yes

**Although based in this definition, the policy adjusted it to fit its objective.

Based on socioecosystem attributes described in Table 1, PACC-ANP and ENBioMEX are identified as the policies that better include the socioecosystem perspective widely including nine out of ten attributes, while moderately including one of them. They are followed by ECCAP, widely including seven attributes. Contrary, LEMPI does not include a socioecosystem perspective, incorporating none of the analyzed attributes, followed by G-ANR and REG-LCC-DF, moderately including one and two attributes,

207 respectively. 44% of the policies adopt the socioecosystem perspective, by including – either moderately
208 or widely – six or more of the socioecosytems' attributes (Table 4).

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210 *Table 4. Diagnosis of socioecosystems attributes in the selected climate change Mexican policies. Categories of attributes' adoption*
211 *(see Table 1) are shown in colors: green for widely adopted attributes; yellow for moderately adopted attributes; red for not*
212 *included attributes. Numbers refer to the occurrences which a specific concept or idea was mentioned (see Table 1).*

Public policy	Year of revised publication	Ecosystem approach	Integrated drainage basin approach	Interdisciplinary approach	Environmental mainstreaming	Public-private financing	Participation	Sustainable / Sustainability	Long-term vision	Monitoring and evaluation	Adaptive management
REG-LCC-DF	2012		0		1			0			
ENCC	2013	9	4		20			73			
LEMPI	2014		12		0			0			
ATLAS-PR	2014	1	1		0			0			
PECC	2014	1	12		3			57			
ECAPP	2015	15	1		18			37			
DRV	2015	8	0		0			19			
PCC-ENT	2015	2	8		0			0			
LACC-JAL	2015	3	8		1			69			
ENBioMEX	2016	65	66		9			870			
G-ANR	2016		3		1			0			
ERCDMX	2016	1	16		0			48			
ENAREDD+	2017	8	0		11			136			
LCC-CDMX	2017		0		4			14			
VUL-MEX	2018		2		0			31			
PEACC	2018	1	128		1			39			
PACC-AO	2018	3	4		0			5			
PAC-XOCH	2018	2	2		0			13			
ANVCC	2019	12	126		2			30			
PSADER	2019	2	4		0			62			
PLAN-JAL	2019	2	18		0			9			
LGCC	2020	12	1		14			56			
NDC	2020	12	2		1			23			
PNH	2020	10	60		3			11			
LGPC	2020		0		2			1			
PACC-ANP	2020	5	9		2			16			

ELAC-PAC-CDMX	2021	9	59		1			284		

Concerning the Ecosystem approach attribute, references to the relation between the natural and the social system occurred 183 times. ENBioMEX contains more occurrences (35.5% of the total), followed by the ECCAP (8.2%), and LGCC, NDC, and ANVCC (6.6% each). These policies add up the 63.6% of references to this attribute. Considering all policies, 44% of them refer to an interdependent relation between the natural and the social systems, which is consistent with a socioecosystems perspective; while 33% refer to a traditional ecosystem approach, in which no influence of society on ecosystems is perceived. 22% of the policies do not express any ideas that refer to this relationship (Table 4).

Relating to the Integrated drainage basin approach attribute, the concept basin appears a total of 546 times in the text of the policies. 23.4% of the mentions were registered on PEACC, followed by ANVCC (23.1%), ENBioMEX (12.1%); PNH (11%); and ELAC-PAC-CDMX (10.8%). Altogether, the mentions registered in these policies add up to 80.4% of the total. About the Environmental mainstreaming attribute, a total of 94 mentions were identified. 21.3% of them were found at ENCC, followed by ECCAP (19.2%); LGCC (14.9%), and ENBioMEX (9.6%). The four mentioned policies add up to 64.9% of all mentions. Finally, concerning the Sustainable/Sustainability attribute, the concepts sustainability/sustainable were mentioned 1903 times in all public policies. 45.72% of the total mentions appear on ENBioMEX; followed by ELAC-PAC-CDMX, with 14.92% of the mentions. Both policies add up to 60.64% of all mentions (Table 4).

The most adopted socioecosystems' attributes are Participation, Ecosystem approach, and Sustainable/Sustainability, used by 85.19%, 77.78%, and 62.96% of the policies, respectively. Opposing, Adaptive management and Long-term vision are the least used attributes, used by 11.11% and 25.93% of the policies, respectively. In general, planning, and national policies better reflect the socioecosytem perspective; while regulatory and municipal policies are the ones that do not include this perspective (Table 4).

Conceptualization and operationalization of CCV by Mexican practitioners

A total of 14 interviews were conducted, one of them being an interview with two people. Eleven women and four men who voluntarily participated belonged to different sectors: public (federal and subnational levels), academy, international organizations, and non-governmental organizations (national and regional levels of scope) (see Figure 1).

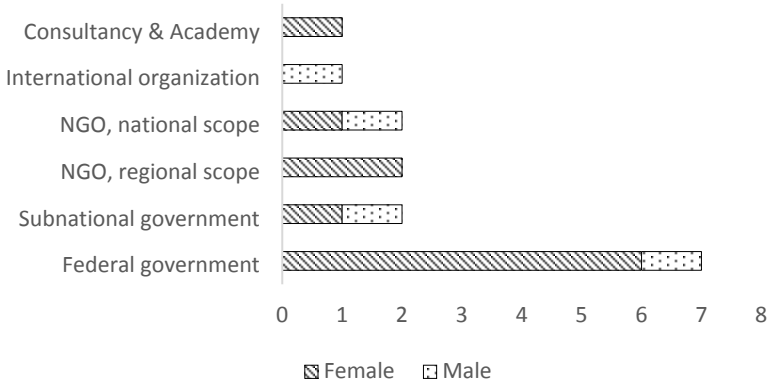
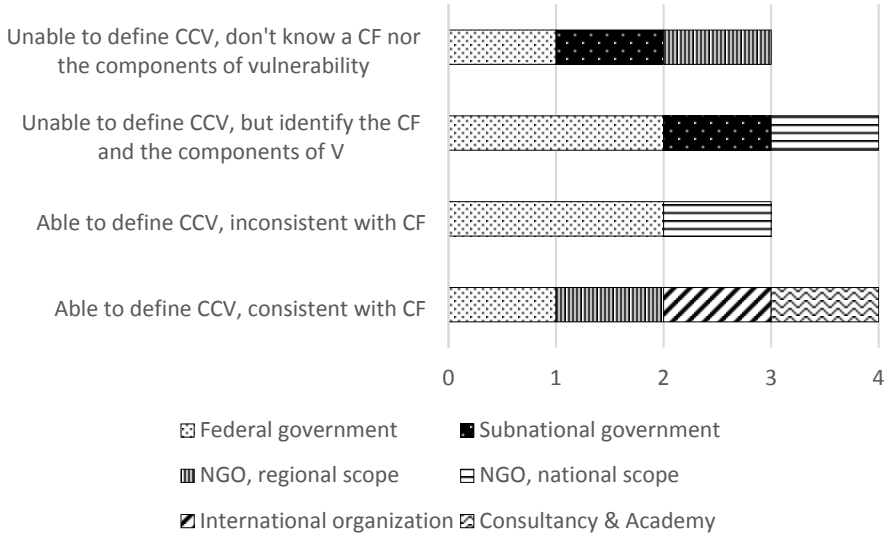


Figure 1. Interviewees' gender and sectors.

Interviewees were asked to define CCV. Half of the interviewees (47%) were able to define it, based on IPCC frameworks: three out of 15 interviewees (20%) referred to the inability to respond or cope with CC impacts (AR4); four (27%) mentioned the susceptibility or predisposition to suffer negative impacts or to be affected (AR5). While the other half of interviewees (53%) did not define CCV, seven of them (47%) named the conceptual framework they use or the components of CCV as they characterize it, i.e. "We use the 2007 IPCC definition AR4 since it is the one stated at the LGCC"; "the three components of CCV – exposure, sensitivity and adaptive capacity (AC)– helped us to develop a territorial analysis"; "assessing physical vulnerability is simple because it is related to infrastructure and relates to risk analysis". Regarding the conceptual framework they use: 73% referred to the IPCC's frameworks (either AR4 or AR5), two interviewees (13%) referred to a risk theory framework (social and physical vulnerability), while 13%

255 did not refer to any conceptual framework. Most interviewees (60%) stated that CCV is a function of
256 exposure, sensitivity, and adaptive capacity (Figure 2; Table 5).



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258 *Figure 2. Interviewees that defined CCV and/or state a conceptual framework (CF) to study it.*

259 Half of the interviewees (53%) are consistent in the way they define CCV, the conceptual framework they
260 use, and its components (See Table 5, marked in green); one interviewee was partially consistent since the
261 interviewee referred to both IPCC conceptual framework (marked in yellow); two interviewees were
262 inconsistent, referring to definitions that do not link to the referred conceptual framework or its
263 components (marked in red).

264 Concerning the nature of CCV, all interviewees identified that it depends on the intrinsic
265 characteristics of the system, which are built on a progressive and constant historical basis. However, 40%
266 of interviewees additionally identify that CCV needs to consider that climatic threats can exacerbate the
267 vulnerable status of a system in one single stressor event, or at a faster rate, which cannot necessarily be
268 interpreted as "historical". On the other hand, 20% of interviewees expressed that exposure to climatic
269 threats does not determine vulnerability, while 27% of interviewees referred to vulnerability as being
270 dependent on the exposure to it, or that the threat is also intrinsic to the system and related to
271 vulnerability (Table 6).

Regardless of the CCV definition or the conceptual framework used, interviewees recognized that the concept has been useful for providing data and baseline for policies design (33%); designing cross-cutting policies (7%; one interviewee); promoting adaptation to CC (7%); developing indicators (7%); building capacity for planning (7%); linking non-related sectors (7%); getting financial assistance (7%). In this regard, developing CCV assessments has been useful for developing appropriate policies for reducing CCV (67%) and promoting CC adaptation (47%); identifying what/who is vulnerable and its causes (40%); quantifying possible losses (7%); rising funds for policies' implementation (7%); communicating the urgency for addressing CC (7%). One interviewee stated that CCV assessments are needed to reduce hazards, while two interviewees also stated that CCV assessments help to measure and to increase resilience. It is also recognized that they are useful for M&E policies (7%), and to link sectors (13%).

About the socioecosystem perspective, nine interviewees (60%) considered it should be the starting point for CCV assessments. Some expressed ideas are: "The social and the environmental parts of a system are indivisible; as societies, we are part of complex systems that involve ecosystems"; "Environment and nature are intrinsic to the system"; "Without nature, we are not able to survive or to deal with threats". However, only five of them (33%) state that basins should be the units for studying CCV. Moreover, only one interviewee (7%) has incorporated a basin approach while developing CCV assessments. The identified difficulties in incorporating this perspective include the scale for available data, and barriers to coupling the basin level to political-administrative units. On the other hand, while some interviewees identify that environment is the basis for reducing sensitivity or increasing adaptive capacities, just 20% weighed environmental and biological elements higher than other elements when analyzing CCV (Table 5).

Table 5. Synthesis of definitions, conceptual frameworks, components, conceptualizations of CCV, and socioecosystem perspective used by interviewees. Green indicates coherency between referred elements; red indicates no coherency between elements; yellow indicates partial coherency between elements. In components, E: exposure; S: sensitivity; AC: adaptive capacity.

No.	Definition	Conceptual framework	Components	Conceptualization of vulnerability	SES perspective**
1	**AR4**	AR4	**E, S, AC**	Outcome	YES, B
2	**AR4**	AR4 / AR5	**E, S, AC**	Contextual	YES, B
3	**AR5**	Risk	-	Contextual	No
4	-	AR4	E, S, AC	Outcome	YES
5	**AR5**	IPCC	E, S, AC	Outcome/contextual	YES
6	-	AR4*	E, S, AC	Contextual	YES, B
7	-	AR4*	E, S, AC	Contextual	YES, B
8	-	IPCC	-	Outcome	No
9	**AR5**	AR5	E, S, AC	Outcome/contextual	YES
10	-	Risk	S, AC	Contextual	No
11	-	IPCC	-	Outcome/contextual	No
12	-	AR4	E, S, AC	Not expressed	No
13	**AR4**	IPCC	**E, S, AC**	Outcome/contextual	YES, **B**
14	-	-	E	Contextual	YES
15	**AR5**	-	-	Not expressed	YES, B

AR4* Definition adjusted to fulfill specific needs.

**SES perspective: B: interviewees recognized basins as units for developing CCV assessments.

Interviewees identify constraints and enablers for CCV analysis, which are categorized as operative, conceptual, and methodological (Table 6). It stands out that to respond to specific needs, flexibility for using one or another conceptual framework is required. Also, since there are no methodological guides to operate any conceptual framework, own technical knowledge and experience is required to specifically define concepts and thresholds between CCV components. Moreover, it is important to consider data availability, according to the scale and level required.

Table 6. Constraints and enablers for analyzing climate change vulnerability, categorized as conceptual, methodological, and operative. In parenthesis, the number of interviewees, out of 15, that mentioned each element.

Type	Constraints	Enablers
Conceptual	- Risk approaches: greater uncertainty (1) - IPCC: refer to a specific moment; exclude drivers (3) - IPCC AR5: limited conceptualization of risk (1)	- IPCC AR4: simpler; less uncertainty (2) - Risk approaches: refer to processes (1) - Use different conceptual frameworks, according to specific needs (3)
Methodological	- Risk approaches and AR5: need to infer the probability of impact (1) - Need to characterize vulnerability according to a specific climate hazard (1) - Difficulty in incorporating scenarios, other than climatic ones (1) - No methodological and operative guides (3) - Identifying appropriate territorial unit (1) - Incorporating complexity related to different scales and levels (2) - Subjectivity related to defining what is classified as each component of vulnerability (8)	- Establish own criteria to define CCV components (3) - Use available tools (1) - Avoid social elements in sensitivity (1) - Establish a level of reference, then include information on other levels (2)
Operative	- Required time and resources (4) - Limited data and repositories (6)	- Use available data, under constant generation (2) - Participative and collaborative processes (2) - Adapting conceptual framework according to the context (1) - Focus on local level (2)

IV. Discussion

The IPCC frameworks have gained ground in Mexico, being the most applied in policies and by practitioners, followed by frameworks from the risk-management approach (Tables 3 and 4). The adoption of these frameworks into local policy is a trend of almost all countries so that they comply with agreements and treaties since they compile the state of knowledge about CCV and are used for the formulation of international standards (Estoque et al., 2023).

Even though it would be expected that all policies used AR4 – since it appears in LGCC; it has been used for a longer period; and the capacity to be applicable in different contexts (Ishtiaque et al., 2022) – AR5 has also permeated in Mexican policies. In this regard, AR4 conceptualizes CCV as an outcome, meaning that CCV is a function of exposure to the hazard, and the dose-response of the system to it (sensitivity). Exposure is considered the driver of CCV, and CCV is an *ex post* and static condition to exposure (K. O'Brien, Eriksen, et al., 2004; Sharma & Ravindranath, 2019; Soares et al., 2012). On the other hand, AR5 considers CCV as an inherent property of the system, which exists independently of the exposure to a hazard and, therefore, is a precondition to vulnerability, which is a contextual conceptualization (Ishtiaque et al., 2022; Nguyen et al., 2016; K. O'Brien, Eriksen, et al., 2004; Sharma & Ravindranath, 2019). The risk framework used by some policies also considers the hazard as an external factor to vulnerability, while giving greater importance to the characterization of the hazard.

Although IPCC conceptual frameworks are the most used by practitioners (Table 4), evidence suggests that they have not been internalized (Tables 4 and 6). This lack of understanding from practitioners trespasses to the development of policies, in which contradictions also exist (Table 3). Challenges for using both IPCC conceptual frameworks, either AR4 or AR5, were identified (Table 6), as well as critics. First, although the IPCC provides definitions for the components of CCV (Figure 2), there is ambiguity as to what they refer to (Table 6) (Eakin & Luers, 2006; Füssel & Klein, 2006), which makes them difficult to measure or characterize (Beroya-Eitner, 2016; Lauerburg et al., 2020), and to standardize for comparisons (Nguyen et al., 2016). For AR4, CCV is described as a function of exposure and sensitivity to a hazard or stress, and adaptive capacity (AC) (Figure 3) (Berrouet et al., 2018; INECC, 2017; IPCC, 2014b; Johnson et al., 2016; Nguyen et al., 2016). Exposure seems to be easily characterized (Table 6). However, the characterization of sensitivity and AC represents a bigger challenge. While sensitivity is defined as the degree to which a system is modified or affected (either adversely or beneficially) by climate-related stimuli; AC is the "ability or capacity of the system to cope, adapt or recover from the effects" from such

stress (CICC, 2018; De Lange et al., 2010; INECC-PNUD, 2018; K. O'Brien, Leichenko, et al., 2004; Sano et al., 2015; Zang et al., 2017). According to interviewees, it is difficult to differentiate one or the other. To surpass this limitation, some practitioners and policies establish their boundaries based on their technical and professional experience. This is the case of ANVCC, which defines intrinsic characteristics key of socioecosystem as sensitivity, while adaptive capacities are extrinsic characteristics that can be learned, achieved, built, or developed (mainly institutional capacities, policies, and financial capabilities).

Contradictory to what Sharma and Ravindranath (2019) state, using AR5 conceptual framework carries one more constraint. In this case, exposure is a variable independent of vulnerability, but which needs to be analyzed to measure the risk of climatic hazards (Figure 3). In practice, this type of exposure seems to be difficult to measure, due to the absence of data and tools, as well as capacities to deal with uncertainty (operative constraints) (Table 6).

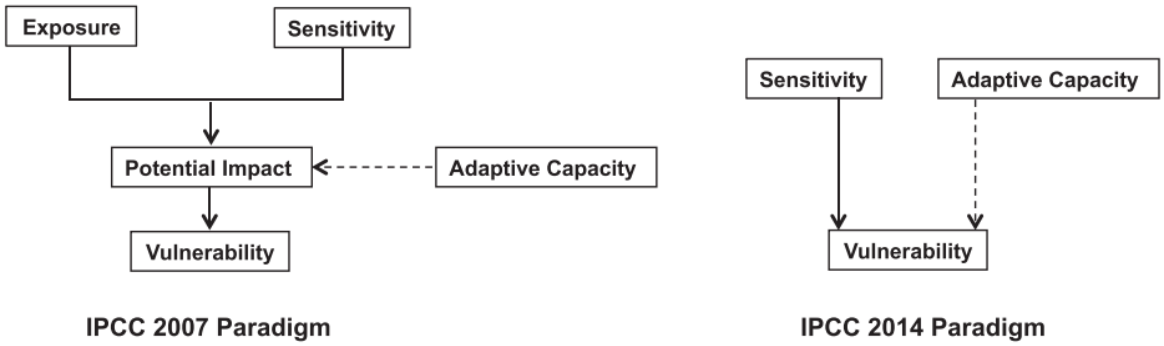

Figure 3. Conceptual frameworks for climate change vulnerability, according to the IPCC 2007 and IPCC 2014 (AR4 and AR5 reports). Source: (Sharma & Ravindranath, 2019).

Alarmingly, there are no guidelines for the use of any of IPCC conceptual frameworks, and practitioners are led to create operationalizing methodologies based on their understanding (Table 6). In this regard, there is an opportunity area for the IPCC to develop applied cases and specific guidelines. Moreover, an opportunity for local scientists and practitioners to create their methodologies, based on the Mexican context.

It is outstanding that, even when the IPCC conceptual framework is not based on a resilience approach, many policies identify it as a related concept that influences CCV (Tables 3 and 4). In this regard, it must be said that outcome vulnerability (AR4) is argued to hinder the complexity of socioecosystems (Ford et al., 2010; Mimura et al., 2014; K. O'Brien, Eriksen, et al., 2004; Turner et al., 2003); while contextual vulnerability may disassociate the biophysical context from the social processes that builds CCV (Ishtiaque et al., 2022). However, the shift in conceptualization from AR4 and AR5 may also reflect a transition to an integrated approach (Mac Gregor-Gaona et al., 2021), where nested hierarchy that shapes socioecosistems is expressed, through biophysical conditions (expressed through exposure), directly impacts the social system.

Under the scope of socioecosystems, scholars have identified similarities and complementarity between the concepts of vulnerability and resilience (Gallopín, 2006; Renaud et al., 2010). From this perspective, it seems that sensitivity refers to elements that influence resilience (biophysical elements); while AC refers to the social sphere. Therefore, relating these concepts may reflect an intention to transit to a more integrated approach, in which interaction between the social (human) and the natural (biophysical) subsystems can be conceived, without arbitrary frontiers between them (Adger, 2006; Ford et al., 2010; Gallopín, 2006; Lauerburg et al., 2020), as well as recognizing the foundation of social processes on biophysical ones. It could also mean a transition to CCV assessments in which the social and the environmental implications of vulnerability are equally weighted, evidencing that humans can affect the environment and that humanity, as well as other species, can be affected by environmental changes (Binder et al., 2013; Eakin & Luers, 2006). Using this perspective, it would be also possible to understand the transescalarity and panarchy of CC and socioecosystems (Folke, 2006; Füssel, 2007; Murray-Tortarolo, 2020), and incorporate it into CCV assessments.

The role that resilience plays in CCV, however, is not completely clear. It has been considered part of CCV components (Ford et al., 2010; Füssel, 2007; Smit & Wandel, 2006; Worm et al., 2006), either as an

intrinsic element of the system that diminishes its sensitivity (Janssen et al., 2006; Lauerburg et al., 2020; Levin, 1998) or as part of their AC (Chapin III et al., 2004; De Lange et al., 2010; Folke et al., 2009). It has also been considered as the opposite condition to CCV (Beroya-Eitner, 2016; McCarthy, James et al., 2001; Renaud et al., 2010), so enhancing resilience to hazards contributes to reducing CCV.

The dominance of the outcome conceptualization of CCV is reflected in the low adoption of the integrated, socioecosystem approach in policies (Tables 4 and 5). Also, although 75% of practitioners conceive that CCV should be studied through this approach, in practice the approach is not being used. In this regard, the absence of national databases, containing information and indicators for measuring CCV at different scales and levels – focusing on basins – limits not only the possibility of developing and replicating robust analyses (Table 6) but of incorporating the socioecosystem approach.

To surpass methodological and operative constraints, the ANVCC could become the policy that not only provides metrics of CCV but also data and indicators on which such metrics are based so that other sectors and stakeholders can use it. It could also become the tool for long-term monitoring, required to evaluate socioecosystems (Fischer et al., 2015). Moreover, georeferencing data could be an angular step for facilitating the development of analysis at a basin scale (Challenger, Cordova, et al., 2018), surpassing geopolitical limitations.

Finally, some policies and assessments are based on IPCC frameworks, but are being modified or adapted according to specific needs (Tables 4 and 7), which may reflect that conceptual frameworks are in the process of being appropriated (Arroyo-Arroyo et al., 2022). However, the not fully understanding of conceptual frameworks could reflect a disconnection between policymakers behind the development of global frameworks and their users. It may also show that the developed frameworks not necessarily are useful for the Mexican context (Arroyo-Arroyo, Aranda-Fragoso, y Castillo 2022). Therefore, institutions, practitioners, and decision-makers involved in CC must take time to: reflect on the usefulness of global frameworks; generate common floors of understanding of CCV in Mexico; come together to discuss and

411 create locally appropriate ones; and detonate harmonized and effective policies based on common goals
412 and objectives.
413

414 V. Conclusions

415

416 Many approaches have failed to address environmental change and, consequently CC, by themselves (K.
417 O'Brien, 2006). Thus, the three knowledge lineages for studying CCV have complemented the other and
418 contributed to the development of integrated approaches (Eakin & Luers, 2006), that consider its multiple
419 dimensions and greater complexity (Soares et al., 2012). However, there are still important constraints
420 when studying CCV: the design of proper and consistent policies under specific frameworks; the limited
421 guidance for applying the theory into practice; and the difficulty of incorporating a socioecological
422 perspective.

423 To surpass these barriers, a national effort spearheaded by public leading institutions in the field
424 should be promoted, ensuring the understanding of the approaches and their correct use in sectoral
425 policies. The academy and practitioners should also contribute by sharing available data, but also sharing
426 their results, as well as knowledge, learned lessons, and best practices for understanding CCV.

427 One of the biggest contributions of the CCV concept is reducing its drivers and promoting CC
428 adaptation, through the design of cross-cutting public policies. It must be recognized that most analyses
429 incorporate a multidisciplinary and multidimensional perspective. However, it must be pointed out that
430 methodologies must be developed, so that replicability and monitoring & evaluation become intrinsic
431 characteristics of any CCV assessment. In the end, doing so will provide the tools for determining whether
432 we are getting closer to meeting our adaptation goals.

433 Ongoing modifications and adaptations of existing conceptual frameworks to specific needs refer
434 to a process of knowledge appropriation. Although there is no universally agreed conceptualization of CCV,

435 none is necessarily better than the rest (Ran et al., 2020), these adaptations could lead to one that is better
436 understood by practitioners and, therefore, better applied under the particularities of local conditions.

437 VI. References

438

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VII. Appendix

Semistructured interview script

1. What is the main objective for studying CCV?
2. What has been the main impact of using CCV concept?
3. How do you define CCV?
4. CCV can be conceived as an a priori condition to exposure to a hazard, as a condition that results from the interaction with a hazard and the system's incapacity to deal with it, or as a combination of both. Are you inclined to think about CCV in a specific way? Why?
5. What role does a climate hazard play in CCV?
6. What conceptual framework (CF) do you use to study CCV? Why?
7. Which are the components of CCV that you use for your assessment/operationalization? How do you define each one and establish boundaries between them? How do you measure them?
8. What other concept is linked to CCV and is not included in the CF you use? What is its relationship with CCV?
9. Can different scales be included when analyzing CCV?
10. Would you consider that CCV analyses have an environmental, social, or socio-environmental perspective?
11. Do you think that biophysical and social dimensions are equally important? How do you measure them?
12. What unit of analysis to study CCV? How are boundaries established?

13. Do you consider historical, current, or future conditions?

14. What type of knowledge is used for CCV analysis?