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Enhancing interoperability to facilitate implementation of REDD+: case study of Mexico

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ABSTRACT

There is an increasing need for approaches to determine reference emission levels and implement policies to address the objectives of Reducing Emissions from Deforestation and Forest Degradation, plus improving forest management, carbon stock enhancement and conservation (REDD+). Important aspects of approaching emissions reductions include coordination and sharing of technology, data, protocols and experiences within and among countries to maximize resources and apply knowledge to build robust monitoring, reporting and verification (MRV) systems. We propose that enhancing the multiple facets of interoperability could facilitate implementation of REDD+ programs and actions. For this case, interoperability is a collective effort with the ultimate goal of sharing and using information to produce knowledge and apply knowledge gained, by removing conceptual, technological, organizational and cultural barriers. These efforts must come from various actors and institutions, including government ministries/agencies, scientific community, landowners, civil society groups and businesses. Here, we review the case of Mexico as an example of evolving interoperability in developing countries, and highlight challenges and opportunities for implementation of REDD+. Country-specific actions toward a higher degree of interoperability can be complex, expensive and even risky. These efforts provide leadership opportunities and will facilitate science–policy integration for implementation of REDD+, particularly in developing counties.

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Objectives of the global climate mitigation program "Reducing Emissions from Deforestation and Forest Degradation, plus improving forest management, carbon stock enhancement and conservation (REDD+)" require the development of national strategies or action plans to determine reference emission levels and implement policy approaches to reduce CO_2 emissions [101]. The challenge for scientists and decision makers is to develop fair, equitable, and country-specific plans that integrate policymaking and research with carbon and biodiversity conservation, mitigation and adaptation to global environmental change [1]. As incentives increase for implementation of REDD+, a variety of networks, institutes and informal locally organized initiatives participate at the science–policy interface [2]. These efforts aim to improve systematic measurements and monitoring of forests to aid in REDD+ design and implementation [3]. While these efforts gain momentum, there are parallel requirements to improve our ability for constant sharing and archiving of information [4,5]. Thus, there is a need to coordinate and share technology, data, protocols and experiences to maximize resources and foster implementation of REDD+. Arguably, this can only be achieved by increasing interoperability within and among countries.

Interoperability is broadly defined as the ability of a system to work with or use the parts of another system [6]. We propose that interoperability is an organized collective effort needed to foster development and implementation of REDD+ programs and actions. For this specific case, interoperability has the ultimate goal to maximize sharing and using information to produce knowledge and apply the knowledge gained, by removing conceptual, technological, organizational and cultural barriers (Figure 1). Interoperability for

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REDD+ should include efforts and commitments by a wide range of actors and institutions that include government organizations/ministries/agencies across different levels of government, and between governments, the scientific community, landowners, civil society groups and business. Conceptually, a low degree of interoperability results in lack of data sharing, diminished communication and a weak science–policy interface that limit implementation of national and international guidelines (Figure 1). The more that efforts are made to successfully bridge the gaps and alleviate the barriers of interoperability, the higher the degree of interoperability (Figure 2). Ultimately, we propose that improving the multiple facets of interoperability will result in higher adaptive management [7] and governance [8], and could facilitate regional-to-global collaborations to foster development and implementation of REDD+.

A high degree of interoperability is particularly critical to address social-ecological challenges related to REDD+, mainly in developing countries. Enhancing interoperability is critical for improving observations (e.g. changes in carbon stocks and fluxes over time and space), forecasting capabilities, and application of innovative technologies (e.g. remote sensing, digital imagery, micrometeorology) to determine how to anticipate, recognize and manage country-specific carbon resources across social-ecological systems [4,9,10]. Higher interoperability could close the gap between research and policymaking communities, so efforts can be more efficient to address important social aspects of REDD+ strategies [11,12]. For example, new information may aid in determining how to distribute payments more equitably for carbon management to benefit poor rural communities [13] by reducing uncertainty in carbon storage potential and making REDD+ management strategies more likely to succeed. Furthermore, higher interoperability could optimize efforts and resources to provide more transparent and robust monitoring, reporting and verification (MRV) systems with the ultimate goal of implementing REDD+ programs and actions.

Here, we outline a conceptual framework of interoperability, and present Mexico as a case study of evolving interoperability for implementation of REDD+. Mexico has been recognized as a non-Annex I country

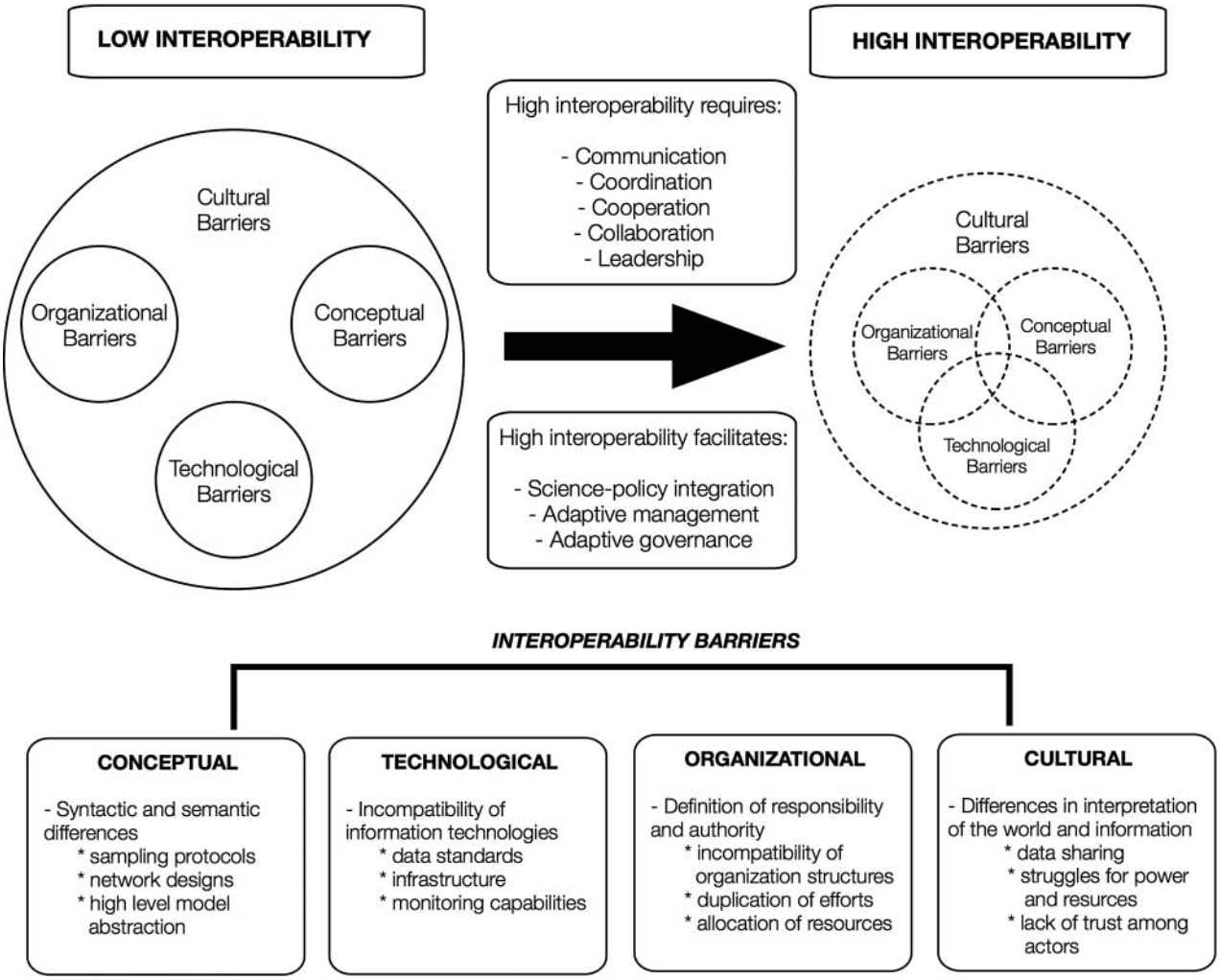

Figure 1. Conceptual diagram of interoperability barriers (i.e. conceptual, technological, organizational, cultural) showing how they interact to enhance interoperability to facilitate implementation of REDD+ programs and actions.

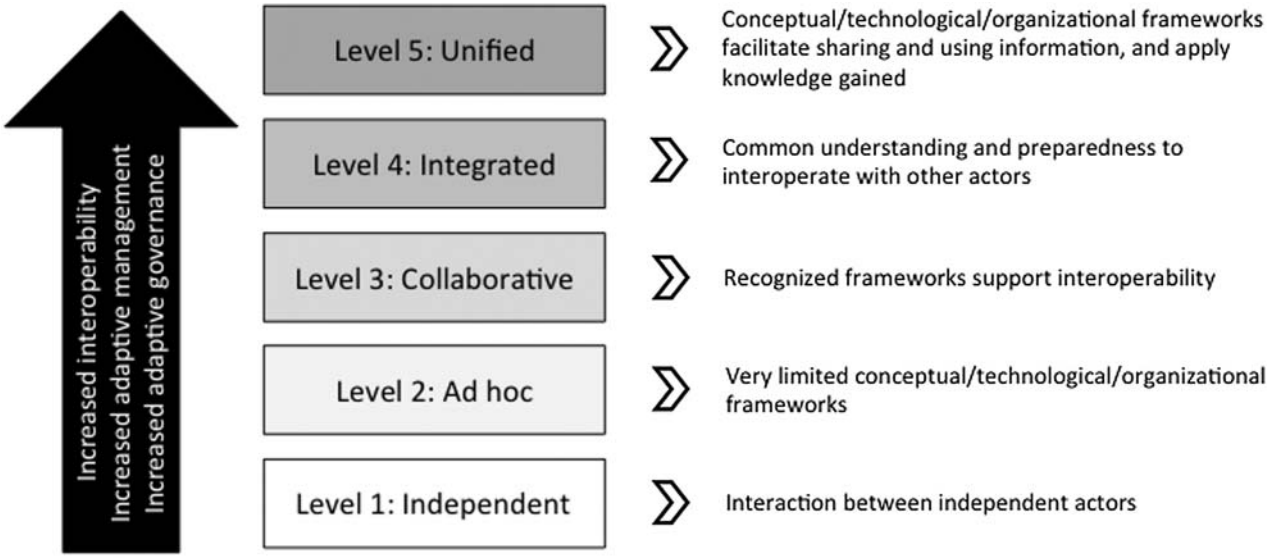

Figure 2. Modified concept of interoperability maturity levels (IML) where higher levels increase interoperability, adaptive management and responsiveness to facilitate implementation of REDD+ programs and actions.

(Annex I of the United Nations Framework Convention on Climate Change (UNFCCC) are industrialized (developed) countries and economies in transition) with the potential capacity to effectively implement the REDD+ strategy [14]. Mexico has similar challenges and opportunities to other developing countries that could benefit from higher interoperability. We recognize that although there are generalities for interoperability, there are multiple country-specific situations and requirements that should be addressed on a case-by-case basis. The ultimate aim of this manuscript is to encourage discussion about barriers that limit interoperability and inspire our stakeholder communities toward development of solutions to enhance interoperability for implementation of REDD+ programs and actions.

Identifying barriers for interoperability

Three categories of barriers for interoperability have been previously identified [6]. These are conceptual, technological and organizational; and here we propose a fourth – cultural barriers – that embraces the previous three (Figure 1). First, there are *conceptual barriers* that include syntactic and semantic differences of information to be exchanged among the different actors involved [15]. Addressing these differences could aid to improve conceptual frameworks and protocols that further enhance the ability to share data and knowledge when, for example, designing a national forest inventory, a monitoring network, or an MRV system for REDD+. Inclusions of clear syntactic and semantic descriptions of REDD+ topics are needed. These include (but are not limited to) transparent and robust MRV protocols, conceptual models and accounting systems for reporting emissions, and approaches for identifying priority areas for implementation of REDD+. This will require national efforts and partnering with other experienced communities (e.g. Earth System Information Partners) to co-develop the needed national and international guidelines/protocols that are most appropriate for MRV and REDD+ in a particular country.

Second, there are *technological barriers* that refer to the incompatibility of information technologies. These problems concern the standards to acquire, process, store, exchange and communicate the data related to development and implementation of REDD+ [4]. Some of these technological issues have been identified as *data interoperability* issues [5]. Addressing the technological barriers to data interoperability in developing countries will likely first rely on low-cost approaches toward standardization (e.g. use of open-source software, standardized data formats such as Network Common Data Form (netCDF)) and sharing of locally or freely available data (e.g. open data policy, common data architectures). On the other hand, technological standardization of equipment and infrastructure may be impossible for projects in developing countries, or will be incompatible with other national priorities and standards. Open discussion forums to co-develop and resolve needs about economic and human resources and a cost–benefit analysis for investment are needed to reduce technological barriers. This is particularly important in light of growing interests and mandates to produce consistent and verified country-specific information.

Third, there are *organizational barriers* that relate to current institutional responsibility and authority, and incompatibility of organizational structures. This third category is more evident in developing countries (but not exclusively) where the organizational responsibilities may not be clearly defined, and there can be high

turnover of governmental personnel and political directives so that with each turnover new collaborations have to be developed [16]. Furthermore, there could also be different government structures/agencies with competing mandates for development/implementation of policies and to access economic resources. Thus, efforts made toward improving the organizational boundaries themselves will aid in facilitating the availability of policy-relevant information and knowledge in support of evolving policy perspectives in developing countries.

We propose *cultural barriers* as a fourth category of barriers that embrace and influence conceptual, technological and organizational barriers (Figure 1). Cultural barriers comprise the degree to which the aforementioned barriers are integrated to enhance interoperability, and are country-specific (Figure 1). Cultural issues influence personal relationships/collaborations including different levels of institutionalized corruption or power/competition struggles, and conflicting ideologies or moral values, to mention just a few examples [17,18]. Cultural barriers also influence the perception of data ownership, the timing and speed of how information is collected and analyzed, and data sharing practices to control resources/information [19].

Cultural issues can influence how people interpret information and statements directly related to environmental challenges such as global climate change [20]. They also influence how government agencies behave with different elements of civil society that may involve internal political power struggles for greater influence and control of resources [11,21]. Ultimately, cultural barriers could limit governance by hampering structures and processes to make decisions and share power, resulting in a lack of action or limiting actions of institutions of social coordination [22]. We highlight that cultural issues related to power and competition among government agencies (or other actors) limit interoperability, but also there are participatory efforts that have been working toward reducing organizational and cultural barriers to implementation of REDD+ [23]. We recognize that people within a country and among countries interpret the world in different ways, and, therefore, understanding and working with country-specific culture is critical for the success of REDD+.

Mexico as a case study of evolving interoperability

Mexico, like many developing countries, is characterized by heterogeneous landscapes that include natural vegetation and human-modified land-use types [24]. Mexico is an extensive and megadiverse country with large carbon pools [25–27] where there are extensive efforts toward MRV and carbon monitoring systems [28–30], and evolving institutional capabilities to potentially implement REDD+ [14,31–33]. These ongoing efforts provide the basis for Mexico to enhance protocols for estimating and reporting greenhouse gas inventories (Tier 3) to the UNFCCC. A "Tier 3" approach to reporting as defined by IPCC requires that a country use inventories with repeated direct measurements of the changes in carbon stocks, models parameterized with country-specific data, and country-specific activity data [34]. Here, we highlight some examples of Mexico's efforts relevant to improving interoperability for implementation of REDD+ programs and actions.

Reducing conceptual barriers

Mexico was a pioneer among developing countries regarding mapping and documenting the state of its natural resources (e.g. soils and vegetation types). Between 1968 and 2001, the former National Institute for Statistics, Geography, and Informatics (INEGI, *Instituto Nacional de Estadística, Geografía e Informática*) worked toward defining protocols to generate national geographical information on natural resources at various scales (between 1:1,000,000 and 1: 1:50,000; known as INEGI *Serie I*). Between 1961 and 2013, there have been improvements to five national forest inventories, although just two could be considered country-wide inventories [35,36]. It is noteworthy that these inventories (like many around the world) are limited by a lack of detailed information about quality control and uncertainty, especially at smaller scales where local variability is poorly understood across different landscapes. As a result, there have been efforts to improve monitoring and inventory designs that recognize the importance of systematic and standardized frameworks for improving measurements and reporting of uncertainties across scales [37,38]. Other examples of efforts to reduce conceptual barriers include designing a national roadmap for REDD+, advances in network design for MRV, and conceptual designs for payment of ecosystem services [31] (Table 1).

Reducing technological barriers

There have been several attempts to provide a national-level analysis of emissions and forest biomass, that have been possible as a result of improvements in data availability and remote sensing techniques. The first attempt includes a synthesis of national forest inventories from the Mexican Forestry Commission (CONAFOR; *Comisión Nacional Forestal*) along with estimates of greenhouse gas emissions from land-use change [25]. The second was developed as part of the FAO Global Forest Assessment 2010, where estimates of total biomass and carbon in soils, derived from INEGI land-use maps, forest inventory data and national soil databases, were included [39]. The third was an effort to integrate

Table 1. Major efforts, current limitations, and general recommendations that aid in closing the gap between interoperability barriers for implementation of REDD+ in Mexico. The conceptual framework of interoperability barriers is shown in Figure 1.

Barrier	Major efforts	Major current limitations	Recommendations
Conceptual	- Design of a forest monitoring system - Design of a roadmap for REDD+ - Advances in network design for MRV - Plan for payment of environmental services	- Challenging and slow applicability of the conceptual and practical approaches - Risk on continuity of efforts due to limited human resources, high turnover of personnel, or changes in political views	- Adopt an adaptive management perspective to address changing needs - Increase political will and commitment from all sectors (i.e. government, research, civil society) to follow or coordinate protocols and models to address changing needs - Converge/agree on national-level approaches for detection of forest changes and attribution of these changes
Technological	- Repeated standardized monitoring of forest plots - Application of different remote sensing approaches for forest monitoring (e.g. rapid eye, MODIS, Landsat, G-LiGHt) - Advances in standardization of technological approaches that aid MRV	- Difficulty to maintain high costs of data collection in the near to long term - Limitation in human resources to analyze, interpret and provide value-added products on available data - Lack of transparent cost–benefit evaluations and discussion to make investments toward reducing technological barriers	- Increase within-country and international collaborations to access technology and expertise - Invest in a cohort of human resources to maintain infrastructure, and analyze, share and extract knowledge based on current available data - Investment to maintain current efforts and in future cyberinfrastructure for data access with clear metadata information - Increase capacity of uncertainty analysis to assess existing data sources
Organizational	- Approval of the LGCC - Publication of the Mexico's vision on REDD+ and ENAREDD+ - Establishment of SNIEG as a portal for sharing of data/information	- Application of policies into actions - Overlapping interests for recognition, data ownership, power and access to economic resources -Slow or partial implementation of objectives/obligations described in national laws or commitments	- Increase political will to follow international and national commitments without looking for individual benefits - Enhance relationships between government research and civil sectors to work together toward common and organized goals (i.e. described in LGCC, and ENAREDD+)
Cultural	- ENAREDD+ accounts for inclusion of different social factors - PMC has a thematic area that bring together studies of social aspects - Bottom up scientific network coordination (e.g. Mex-LTER, MexFlux)	- Limited culture on data sharing and data transparency - Lack of trust among government, research and civil sectors -Power struggles and unhealthy competition of resources	- Adopt clear and transparent data-use policies for the benefit of the country - Promote open discussions to increase trust among sectors that considers environmental justice - Transparent use of economic resources that allow clear opportunities to enhance interoperability among government, research and civil sectors - Apply a vision of adaptive governance of social-ecological systems

Notes: ENAREDD+: National REDD+ Strategy; G-LiGHt: Goddard's LiDAR, Hyperspectral & Thermal Imager; LGCC: Ley General de Cambio Climatico; MODIS: Moderate resolution imaging spectroradiometer; MRV: Monitoring, reporting and verification; PMC: Programa Mexicano del Carbono; REDD+: Reducing Emissions from Deforestation and Forest Degradation, plus improving forest management, carbon stock enhancement and conservation; SNIEG: Sistema Nacional de Información Estadísitca y Geográfica; Mex-LTER: Mexico Long Term Ecological Research network; MexFlux: Mexico consortium of scientists using the eddy covariance technique. A description of adaptive governance of social-ecological systems can be found in previous studies [8,22].

available forest inventory information with space-borne optical and radar data throughout the country [32]. Other examples include advances in standardization of technological approaches that aid MRV (e.g. measurements of ecosystem scale carbon fluxes; [30]), and application of novel remote sensing approaches (e.g. Goddard's LiDAR, Hyperspectral & Thermal Imager or G-LiGHt, Rapid Eye; Table 1). These improvements have provided experience and baseline information, but there is still the challenge of information integration, a clear data-sharing policy, and long-term monitoring programs to reduce uncertainty in the estimates and achieve a robust and transparent MRV system.

Reducing organizational barriers

Arguably the most important effort has been the development of the Mexican General Law on Climate Change (LGCC, *Ley General de Cambio Climático*) [102]. This law determines the scope and content of the national climate change policy, defines the obligations of state authorities and provides the necessary institutional mechanisms to address this challenge [102]. The LGCC establishes two key instruments to guide and implement public policy. First, in the short term there is the Special Climate Change Program 2013–2018 (PECC, *Programa Especial de Cambio Climático 2013-2018*) [102]. Second, within a long-term framework is the National Strategy on Climate Change (ENCC, *Estrategia Nacional de Cambio Climático Visión 10-20-40)*. This national strategy works as a guiding document for long-term national climate change policy, describes strategies and responsibilities of different institutions, and identifies key mitigation and adaptation activities for the country [40]. Finally, the *Sistema Nacional de Información Estadísitca y Geográfica* (SNIEG) has been an organizational effort toward governmental

transparency and improved organization of data and information (Table 1).

Reducing cultural barriers

A critical governmental effort to increase social participation is the publication of Mexico's vision on REDD+ (*Visión de México sobre REDD+*) [41], which paved the road for the National REDD+ Strategy (*ENAREDD+; Estrategia Nacional REDD+*) [42]. ENAREDD+ aims to redirect policies and reduce the incentives that promote deforestation and degradation, along with increasing incentives for conservation, management, restoration and the sustainable use of forest resources [42]. Outside the government, the Mexican Carbon Program (*Programa Mexicano del Carbono*; PMC) has the overarching goal to act as a liaison between the research and policy communities. The PMC collects information and organizes annual meetings that promote communication and collaborations among scientists in Mexico on different topics: the social dimension, aquatic and marine ecosystems, terrestrial ecosystems, the atmosphere and bioenergy [29,43] (Table 1). Finally, bottom-up scientific networks are contributing to changing the view of data sharing toward a more open, transparent and replicable science [44].

Opportunities and challenges to improve interoperability

The Paris Agreement that resulted from the 21st Conference of the Parties (COP21) has been an unprecedented effort to define the mitigation actions necessary to remain below the threshold for "dangerous" climate change, and to document country commitments for achieving emissions reduction targets. Unfortunately, the goals of REDD+ may not be met if stakeholders lose trust in REDD+ processes or if there is little or no attempt to coordinate and integrate among the different actors, scales and interests [45]. The examples described above provide a brief summary of how interoperability has evolved in Mexico for implementation of REDD+. Yet, despite these improvements, there is still work to do in order to close gaps among the barriers to improve interoperability and build trust in REDD+ processes.

A variety of models have been developed to guide thinking across a continuum of interoperability degrees [46]. One of these approaches is the interoperability maturity levels (IML) model that consists of a set of levels with different attributes [46]. We use this model as a framework to promote discussion on improving interoperability (Figure 2).

There have been notable advances to reduce *conceptual barriers* by designing monitoring protocols, networks, a roadmap for REDD+, and a plan for payments for environmental services in Mexico (Table 1). However, implementation of these efforts may be hampered by slow action and political changes in views and priorities. Focused knowledge transfer and knowledge sharing should be promoted within Mexico and internationally [47]. This could enhance national efforts and products (e.g. emissions estimates) and ensure that they are compatible with information among countries [34].

Different sectors in Mexico have worked to address *technological barriers* and are opening opportunities to produce knowledge and collaborate internationally (Table 1). These efforts have placed Mexico as a country with high engagement in UNFCC REDD+ processes [14] with an emerging capacity to monitor changes in carbon stocks [28], and showing advances in MRV systems [25,32,44]. Technological barriers can be addressed by increasing collaborations, building on already acquired technological advances/expertise, and with a common vision to share information (national and international). We highlight that limited economic and human resources may threaten the advancements regarding technological barriers in the near to long term.

Mexico has pioneered legislation regarding climate change with the LGCC [102]. This law coordinates efforts toward reducing *organizational barriers* by defining roles and responsibilities, and aims to achieve a higher level of interoperability (Figure 2; Level 5). If this law is fully enforced and its goals achieved, then conceptual, technological and organizational frameworks should be in place to share information and apply knowledge gained for implementation of REDD+ (among other goals). The LGCC has facilitated other policies (e.g. ENAREDD+; Table 1) but much more is needed to translate legislation and policies into actions. Major challenges that must be overcome are the overlapping interests in power and political recognition [48], and there should be a strong willingness to enhance and strengthen relationships among stakeholders to work together toward common organizational goals for implementation of REDD+. This may be promoted by adopting an adaptive management perspective [7] and understanding the social contexts needed to facilitate it (i.e. adaptive governance; [49]), with the ultimate goal to promote the adoption and updating of protocols and models for implementation of REDD+.

Cultural barriers have been considered by the ENAREDD+ and the PMC among other efforts (Table 1). ENAREDD+ accounts for inclusion of different social factors such as perception of land and resource ownership along with topics related to environmental justice [42], and there are proposed plans that consider cultural and social equality for implementation of ENAREDD+ [50]. Despite these efforts, there are multiple cultural issues that must be addressed in order to achieve a higher degree of interoperability. Stronger political will to facilitate political change and

environmental policymaking is needed [48]. Arguably, power struggles at different levels in the government, in academia and across the civil sector create a lack of trust among stakeholders [51,52]. There is a need for open discussions with organized participatory processes to increase trust among actors [53], and empowering communities for environmental governance [54].

Furthermore, there is limited cultural acceptance of data sharing and data transparency that promotes unhealthy competition for resources [44]. This could partially be addressed with stronger political will and timely/transparent implementation of obligations for public data sharing by multiple governmental organizations as is required (but not necessarily enforced) by the SNIEG. Funding agencies should also enforce sharing of data and value-added products [55] to promote the use of available data for synthesis [56] by having clear data-use and data-sharing policies [57]. Finally, international interoperability must consider cultural differences and should rely on tolerance and adjustments of behaviors and expectations [58]. These international efforts will build global ecological understanding and ultimately enhance the implementation of national and international guidelines.

This article proposes that improving the multiple facets of interoperability could facilitate collaborations and foster development and implementation of REDD+. Mexico has shown strong efforts toward reducing barriers to interoperability, and the path (on paper) is set to achieve a higher degree of interoperability (i.e. Level 5; Figure 2). Low interoperability could result in duplication of efforts and uncoordinated programs that lead to unproductive or deficient implementation of national and international guidelines. We recognize that improving interoperability can be complex, expensive and even risky. However, we argue that recognizing and addressing the barriers to interoperability provides leadership opportunities and will lead to increase in production and application of knowledge toward informed decisions and implementation of REDD+ programs and actions. These changes may not happen overnight, but the imperative to advance REDD+ for societal benefit is far too great for past cultural legacies to impede progress. COP21 set high expectations and a coordinated effort is needed to close the gap among interoperability barriers with the ultimate goal to benefit society. The goal is set; are we ready?

Disclosure statement

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