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Measuring Climate Change: The importance of geospatial information with an application to carbon sequestration and storage in the System of Environmental-Economic Accounting — Ecosystem Accounting (SEEA EA)

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Abstract

Climate change (CC), associated with greenhouse gas emissions, has negative effects on economic activities and human well-being. Through certain biological processes, vegetation and soils capture emissions (sequester) and accumulate carbon reserves (store). This process of sequestration and storage of carbon is a service of ecosystems towards economic and human activities, reducing the negative impacts of climate change.

Mexico, as a pilot country of the Natural Capital Accounting and Valuation of Ecosystem Services (NCAVES) project, in collaboration with the United Nations Statistics Division, has been developing Ecosystem Accounting, whose main objective is to measure its assets and services (both in physical and monetary terms) based on the System of Environmental-Economic Accounting - Ecosystem Accounting (SEEA EA). The integration of INEGI's statistical and geospatial information has been crucial in this process, particularly data related to the Land Use and Vegetation Chart, the environment, and ecosystems. These accounts integrate, in a coherent framework, different sorts of information and provide new insights on ecosystem change and use, seeking to improve the measurement of ecosystems and their services at national and subnational levels. Through this accounting scheme it is possible to measure changes in the extension and condition of ecosystems; carry out an economic valuation of its services and assets; and express this information through monetary indicators.

One of the accounts built in this process is the carbon accounting balance, which is developed with the use of information from the National Forest and Soil Inventory of the National Forestry Commission (CONAFOR), among other data, separately identifying the processes of carbon sequestration and storage, linked to the grow of primary (storage) and secondary (sequestration) forests, which allows reducing CO_2 concentrations in the atmosphere. The estimation of the carbon service is consistent with the information necessary to monitor public policy strategies on climate change, such as the Paris Agreement to address climate change and its negative effects, or REDD + (FAO) on reducing emissions from deforestation and forest degradation to mitigate CC.

The integration of statistical data with geospatial information boosts the power of data, resulting in a much greater understanding of social, economic, and environmental issues, than viewing the statistical or geospatial information in isolation.

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Introduction

Natural resources are essential to societies and economies, providing a variety of renewable and non-renewable assets and playing a critical role in the provision of employment, as a source of food, energy and commodities, etc. Due to the increase in population, CO_2 emissions and other global changes (Vitousek, 1992; Camill, 2010), these resources are often over stretched, leading its depletion. So, for humanity, it is of paramount importance to learn how to use these natural resources in a sustainable manner and to ensure that their benefits can be enjoyed both by present and future generations.

On the other hand, the COVID-19 pandemic evidenced that human existence is fragile. The idea of this fragility raised the awareness about the negative impact on human life when the environment balance is disturbed, which raised concerns that, if we do not take urgent action against climate change (CC), the damage could be even greater and more lasting than the effects of the pandemic.

How do we translate concern into climate action? Policy responses are needed.

In order to be appropriately focused, the design of public policy requires objective elements to measure the size and identify the location of the problem. Policies should also come up with the right balance of incentives for the different actors in different places to foster a transition to a low carbon economy and to evaluate the impact of the policies implemented—such as revenues from carbon pricing, cash transfers to compensate actors affected, channel resources towards the production of clean energy and so on. All of this requires adequate measurement. At the international level, there are several initiatives towards this goal, led by the IMF, OECD, Eurostat, among others (i.e. ONU, 2021 (BIOFIN); EPA, 2021 (Green Power)); although further progress on internationally agreed standards is needed.

In the meantime, technological advances in geospatial information offer an ever-increasing amount of geodata. This type of information should be used to make sound decisions for sustainable development and in analyzing factors that affect the utilization of natural resources and have an impact on CC.

Thus, integrating economic and environmental data with geospatial information provides a comprehensive multi-thematic view of the interrelationships in the nexus economy-environment-territory. The purpose should be to measure the full impact of economic activities on the environment and territory, beyond what is traditionally incorporated into the National Accounts, since most of the current measurements do not consider the externalities that affect the environment and those that can preserve it.

For this purpose, the System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA) has been developed. The proposal is a spatially-based, integrated statistical framework for organizing biophysical information about ecosystems, measuring ecosystem services, tracking changes in ecosystem extent and condition, valuing ecosystem services and assets and linking this information to measures of economic and human activity (UN Committee of Experts on Environmental-Economic Accounting 2021). The Natural Capital Accounting and Valuation of Ecosystem Services (NCAVES) project in Mexico allows to measure the flow of ecosystem services such as the provision for crops, carbon sequestration and storage, pollination, water supply, and ecotourism. The results obtained are presented in accounting tables as well as in georeferenced biophysical and monetary data, such as:

- Transition matrices that represent changes in land use and vegetation, where the advance of agriculture and human settlements, as well as changes in the extension of forests and jungles, stand out.
- An ecosystem integrity index was developed. This index allows knowing the integrity degree of the different ecosystems of the country.
- Regarding carbon sequestration and storage, distribution maps of the carbon value in soil and biomass were generated for the entire country.

In Mexico, the National Institute of Statistics and Geography (INEGI), is not only the National Statistics Office, but also the National Mapping Agency. In addition, it has another role as coordinator of the National System of Statistical and Geographical Information (SNIEG by its acronym in Spanish). INEGI´s legal mandate is to ensure that the SNIEG provides society and the State with quality, pertinent, accurate and timely information, to contribute to national development, with the purpose of producing and disseminating information of national interest. The SNIEG regulates and coordinates the generation of statistical and geographical information in Mexico through an institutional design that fosters collaboration among its different member institutions and regulates statistical and geographical activities of the country.

Derived from the above, for INEGI it is natural to integrate complex statistical information, such as National Accounts, with geospatial information. Recognizing the importance of public policies on mitigation and adaptation measures to CC, the role of information on these two phenomena should be brought to the fore and thereby have the chance to gain timeliness and efficiency in climate action decisions. Thus, the implementation of projects that enhance the value of the information from these two worlds, so different but so interrelated as is the case of the SEEA EA, is of paramount importance for INEGI.

The purpose of this paper is to provide an overview of the importance of geospatial information, and its relationship with CC and its economic and financial dimensions. Subsequently, an overview will be given about ecosystems and ecosystem services, continuing with a description of the carbon cycle, with an origin and destination approach, and how it is represented in the SEEA EA, ending with examples of public policies that could be implemented based on the results of this initiative.

1. Background. The importance of Geospatial Information.

Everything happens in some place in planet Earth and each place has its unique characteristics in the physical environment: climate, relief, geology, rivers, lakes, soils, plant cover and so on, as well as in human related/made features and activities: cities, roads, factories, agriculture, fishing, etc. Another unique characteristic of each place is its location, and every location can be determined unambiguously with respect to some spatial reference system. That is the matter of maps or cartography, now also referred too, loosely speaking (and encompassing other types of data) as Geospatial Information.

In the past, maps served mostly for navigation and military uses. Afterwards they have been used as a fundamental tool to know all the way from the Earth (continents, oceans) to countries, regions, cities, and the spatial distribution of the natural resources, as water, soils, forests, and the climate as an example.

Also, everything happens at a given time. So Geospatial Information also incorporates the time dimension, making possible to look not only at the spatial distribution of features and phenomena in a given moment, but also to their changes and processes, and the interrelationships between them.

Climate change (CC) is a process that involves multiple facets, causes, and effects on different features, either natural or anthropogenic. Everything related with CC happens also in some place. So, it is unthinkable to approach CC without the spatial mindset, that is, without maps or geospatial information about everything, even for economic and financial issues, to achieve a holistic vision of CC.

In Mexico, INEGI, as the coordinator of the SNIEG, also works with other government agencies and ministries for a more complete and integrated information infrastructure. This has shown to be vital for a smooth integration of spatial and statistical information for a better characterization of the socio–economic phenomena together with the natural environment in the territory.

The National Geographical and Environmental Information Subsystem within SNIEG coordinates multiple government agencies at several levels: federal (national), regional and local (states). Through the subsystem and several Specialized Technical Committees (i.e, for Basic Geographic Information, Cadastral, Water, Forest Resources, and Climate Change among others) geospatial information needs, technical standards and planning are made for each specific theme. The purpose is to make sure that the needed geospatial information data for public policies (assessment, planning and evaluation) is produced and disseminated.

As the National Mapping Agency, INEGI is in charge of the generation and dissemination of diverse geospatial information. Table 1 lists some examples of geospatial information and its uses.

Table 1. Examples of geospatial information

Geospatial information	Use
National Geodetic Service (Vertical, Horizontal and Gravimetric Networks)	Supports the spatial reference system for all the geospatial information
National Aerial Photography System. (After 2010 it was replaced with high resolution satellite imagery)	Imagery is the base for all the mapping.
Orthoimagery and Digital Elevation Model Production	Representation of the relief, elevation, slope, and others.
Topographic maps	Portrays relief, hydrography, urban areas, infrastructure, places names, among others
Natural resources maps	Map series for climate, geology, water (surface and ground), soils, vegetation and land use.
Geostatistical framework	Spatial Framework for censuses and surveys
Cadastral, land registration	Detailed and accurate spatial data for land tenure-ownership, from land rural land parcels to houses.

Also, INEGI as coordinator of the SNIEG, promotes cooperation with other institutions and agencies through Specialized Technical Committees in the generation of other geospatial information as well as in the elaboration of norms and standards in the matter. The role of INEGI makes possible the setting of an information infrastructure at national level with high-quality, reliable, comparable and standardized data that can help to make informed decisions to cope with climate risks (Buckley, 2021)

1.1 Geospatial information, climate change and its economic and financial dimensions

How is geospatial information related to CC and its economic and financial dimensions? As it has been shown, geospatial information allows us to know the territory, the natural features and phenomena, as well as those that are human related.

With geospatial data we can infer and measure natural causes and effects of CC and from them, economic and financial issues, so that mitigation and adaptation measures for CC are adopted and financed. For example:

- Mapping of climatic variables (temperature, precipitation).
- Emissions of green-house gases (GHG) from land use change–deforestation.
- Carbon storage and sequestration.
- Habitat and biodiversity loss.
- Risks (floods, drought, hurricanes) for human activities and infrastructure.
- Towns, cities.
- Agriculture.
- Infrastructure: roads, buildings, ducts, transmission lines, etc.

Once we recognize the importance of geospatial information, it is important to acknowledge that building SEEA Ecosystem Accounting requires to develop the capabilities that allow integrating different types of data into one coherent framework.

2. Ecosystems, ecosystem services and climate change

The ecological processes of natural ecosystems provide society with a significant amount of free services on which ecological, economic and social stability relies (Sauvé et al., 2017). These services include climate regulation through the sequestration and storage of GHG, improvement of water quality, control of hydrological cycles, protection of coastal areas through the generation and conservation of coral reef systems and sand dunes, generation and conservation of fertile soils, control of crop parasites and vector-borne diseases, pollination of many crops, direct use of food from aquatic and terrestrial environments, among others (CONABIO, 2021). The sustenance of ecosystems functioning lies in their biological diversity. However, native communities and populations are being affected by different global changes, such as the introduction of nonnative species, land use change, deforestation and global CC, the latter mainly influenced by anthropogenic activities.

In light of CC scenarios, the ability of many species to adapt to their environments is being hindered (Tilman et al., 2019). CC is currently affecting 19% of species on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species, although some models suggest that species loss could reach 54% in the next 100 years (Román-Palacios and Wiens, 2020). A recent report by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services showed that 14 of the 18 global ecosystem services assessed were in decline (less biodiverse), but in economic terms, more prosperous (Dasgupta, 2021).

As mentioned before, CC is the result of many interactions between natural phenomena and human activities. In this context, there are several processes that are widely recognized to have also contributed to it, the main ones being the increase in human population, the growing emission of GHG, changes in the use of land or territory, alterations in the biogeochemical cycles specially of water and the components of the atmosphere, loss of biological diversity, high rates of deforestation and acceleration of the desertification process (IPCC, 2016). According to the Intergovernmental Panel on Climate Change (IPCC), between 1850 and 2005, global temperature increased 0.76ºC with a projected increase between 1.4ºC and 5.8ºC by 2100. This global warming will accelerate the extinction of species and will affect the provision of goods and services that are essential for human well-being (Weiskoff *et al*., 2020).

In addition to rising disease rates and habitat degradation, CC is also causing mutations in species themselves, threatening their survival. For example, the climatic scenarios project temperature increases of up to 2 ºC in northern Mexico, while most of these increases range from 1ºC to 1.5ºC, with the most affected ecosystems being the Temperate Mountain Forests (Villers-Ruiz and Trejo-Vázquez, 1998), and will even affect the productive processes of some species, among them, high mountains coffee (Villers et al., 2009).

Regarding the increase in global temperature that is behind CC, the International Monetary Fund mentions that more than 60 programs of emission trading and carbon taxes have been introduced at the regional, national and sub-national levels, whose objectives aim at stimulating the reduction of emissions through this type of financial schemes. A revealing fact in this regard is that a global carbon price of around $75 per ton is needed to reduce emissions enough to keep global warming below 2 ºC (Parry, 2021).

3. Natural Capital Accounting and Valuation of Ecosystem Services Project (NCAVES) and the System of Environmental Economic Accounting - Ecosystem Accounting (SEEA EA)

In 2017, the United Nations Statistics Division (UNSD) and the United Nations Environment Programme (UNEP), in collaboration with the Convention on Biological Diversity (CBD) Secretariat implemented in five strategic countries a pilot project denominated Natural Capital Accounting and Valuation of Ecosystem Services Project (NCAVES). These countries were Brazil, China, India, Mexico and South Africa.

The project proposed the development of pilot tests for the United Nation´s System of Environmental Economic Accounting-Ecosystem Accounting (SEEA EA), with the purpose of improving the measurement of ecosystems and their services, in physical and monetary terms, at the national or sub-national level. It incorporates, in a cross-cutting way, biodiversity and ecosystems as foundations for the formulation and implementation of public policies at the appropriate level and contributes to the development of an internationally accepted methodology and its application in countries.

SEEA EA allows the integration of measurements on the characteristics and functions of ecosystems and the services they provide, with measurements of economic activities and other human activities, adopting a systematic approach that allows the ecosystems´ information on the type, size, location, conditions and the services they provide to be organized in physical and monetary terms. On the other hand, the valuation of ecosystem services in monetary terms makes it possible to make visible the contribution of nature to economic activities and human well-being to support evidenced-based public policies.

Within the framework of the NCAVES project, the extent of ecosystems in Mexico and their state of condition were analyzed taking advantage of the availability of information derived from INEGI´s Vegetation and Land Use Charts, Series III to VI, as well as the Forest and Soil Inventory of the National Forestry Commission (CONAFOR, by its acronym in Spanish). In the first phase, the distribution of ecosystems in Mexico and the area they occupy were documented, as well as the changes that have occurred over 12 years. In a second phase, reference is made to their health status, analyzing the successional stages of vegetation, as well as the incidence of different disturbances that alter or shape the structure and functioning of ecosystems using available geospatial information analysis tools.

The resulting maps of NCAVES Project integrate geospatial information from INEGI and other Mexican institutions (National Commission for the Knowledge and Use of Biodiversity – CONABIO-, CONAFOR, National Commission of Protected Natural Areas -CONANP-) with carbon sequestration information from the Ecosystem Extension Accounts and Ecosystem Condition Accounts. The framework of these maps is composed of basic information (cadastral, protected natural areas, geodesic and topographic information).

The abovementioned inputs served as the basis for the valuation of environmental services in monetary terms, assuming that all goods and services must be valued for their conservation and sustainable use. For example, due to their extension, pine forests (*Pinus sp*.) are considered to be the base of the Mexican forest industry (Del Ángel-Mobarak, 2012); however, the valuation of these forests as carbon storage and sequestration reservoirs is just beginning to be recognized. Another example is the assessment of the nature tourism services, where, although the ecological importance of Natural Protected Areas in this regard is well documented, there is no clear methodology to establish an economic value for them, a different case than valuing in economic terms forest areas producing wood or resins.

4. The carbon cycle: methodological approach of origin and destination

It is recognized that the acceleration of CC is a consequence, to a large extent, of anthropogenic activities, and that the dissipation of CO_2 emissions generated by humans requires the regulation services of ecosystems, in addition to other practices tending to achieve international agreed goals. On the other hand, it is very clear that economic and population growth, as argued above, are deepening the problems related to CO_2 emission beyond a limit that becomes unsustainable.

Knowing what actions must be taken to regain the natural balance of ecosystems, when control programs should be applied (mitigation or adaptation), as well as their impact of reducing GHG emissions, is essential for countries to modify their growth patterns in the current “business-as-usual” style. More sustainable production schemes than those entrenched from the past are urgently needed.

Therefore, having data on the carbon cycle is essential for the design of public policies. Knowledge about both the origin and destination of emissions allows regulation to address not only emission sources—such as transport, generation of electrical energy, industry, or agriculture—but also on promoting in a comprehensive approach programs and actions focused on an adequate management of large CO_2 sinks, such as vegetation, soil or oceans. It is possible to verify that the proper management of these natural assets makes them to function as net carbon dissipators by eliminating more CO_2 from the atmosphere than the emissions they generate.

A comprehensive scheme on the carbon cycle can be recognized by identifying the source of emissions (in as much detail as possible) and their destination, without prejudice to sequestration and storage in large sinks before it arrives to the atmosphere. In Figure 1 the carbon cycle is pictured, where the origin and destination of this type of atmospheric emissions are outlined, differentiating in the destination the large carbon sinks and the CO_2 that goes to the atmosphere. The detail of the data in the cycle design allows locating and mapping the programs and actions to combat CC, differentiating between actions at the source or at the destination of the emissions, defining a proxy for the carbon emitted into the atmosphere, among other advantages.

An important task is to define the information sources that will be used to build the carbon circuit and a coherent framework that allows to integrate different types of data:

- On the CO_2 origin side, there is nowadays a national inventory of emissions for 2015 and a series for 1990-2019 will be released on the 3rd Biennial Update Report of Mexico to the United Nations Convention on Climate Change.
- On the destination side, with the methodological progress achieved through the SEEA EA and the Pilot Study of the Environmental Accounts of the Ecosystems of Mexico, it is possible to have the first data on the sequestration and storage of carbon in soil and biomass.
- As a next step to complement the destination of CO_2, the development of an ocean accounts manual and pilot studies in this regard are needed to provide elements to work on the marine carbon balance. Likewise, biodiversity accounts, also in methodological development, can provide data on respiration and carbon transfer between living beings.

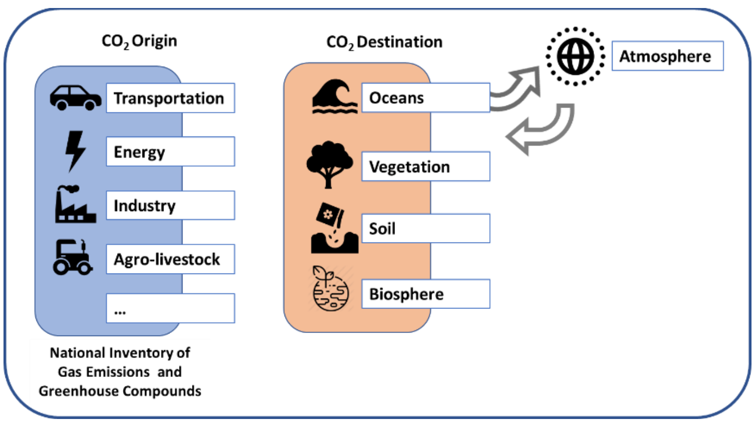


Figure 1. Carbon cycle.

5. Carbon sequestration and storage in the SEEA EA

The compiled knowledge in the Environmental Accounts of ecosystems helps to understand the role of forests as a natural carbon sink on a large scale, by capturing atmospheric carbon through photosynthesis and retaining it in trees as organic matter. This service occurs especially in secondary forests, where plants growth faster than in mature forests. Meanwhile, the soil captures carbon through the respiration of the organisms that inhabit it, particularly when it comes to fertile soils, rich in microorganisms. In addition, the oceans are the main carbon collectors, mainly through phytoplankton and corals. They absorb about 50% of the atmospheric carbon.

The use of CO_2 emissions data, at the source and at the destination level, allows analyzing the relevance and costs of implementing actions to avoid their generation and/or to reduce them once they have been generated by economic activities. Figure 2 shows how an accounting scheme can be derived from the carbon cycle using the approach of origin and destination. In this way, it is possible to observe how the amount of emissions captured and their imputed cost change to a great extent depending on when and where they are made. For example, at the source level, international proposals have been generated to reduce energy consumption, from the use of more efficient vehicles or electrical appliances, buildings with heat gain, etc., to the use of technologies to capture the CO_2 that is emitted by a coal-fired power generating plant and transporting it through pipelines and injecting it into a nearby abandoned oil field, where it can be safely stored. The cost attributed to these practices can be very high, compared to measures such as forest and soil conservation, whose maintenance cost is estimated to be less than the value of the ecosystem services they generate, such as CO_2 capture and storage, climate regulation, pollination, aesthetic services, etc.

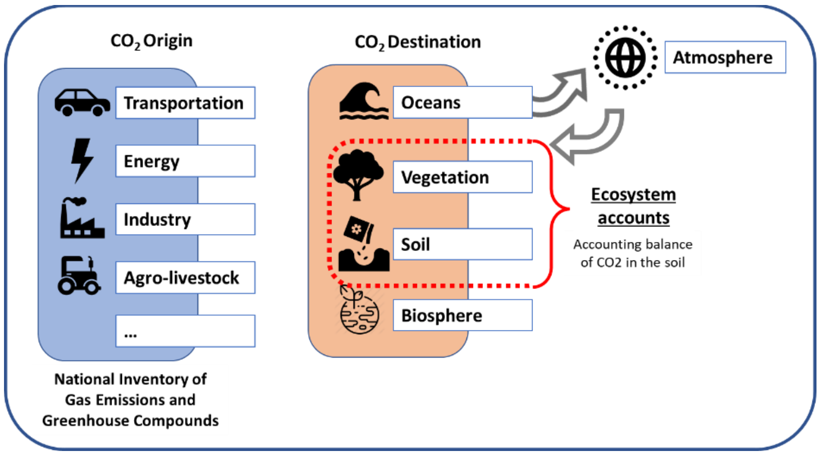


Figure 2. Carbon cycle and SEEA EA

The accounting balance of a country's forests and jungles (or of a defined territorial extension) is combined with the carbon coefficients by vegetation type from the National Forest and Soil Inventory (INFyS) database to obtain a carbon balance. Ecosystem extension maps are also used with the addition of monetary and carbon storage values by vegetation type, which allows us to evaluate carbon stocks over time, as well as the flows and final dispositions, with which it is possible to carry out an examination to determine if it is either an emitting source or a CO_2 capture system (net balance). In this sense, the accounts of the ecosystems of Mexico, in the pilot study, help to start constructing the full global carbon cycle by developing the accounting of the carbon sequestered and stored in the various types of vegetation and soils and assigning a monetary value to these services.

Considering that ecosystems offer a basket of joint services, by investing in the maintenance and sustainable management of an ecosystem (maintenance cost) to increase carbon sequestration and storage services, other externalities are also promoted, such as of pollination of agricultural crops, climate regulation, tourism, aesthetic values, and so on. In addition to the biophysical data from the Mexican pilot study on Environmental Accounts of Ecosystems, the calculation of the monetary value of ecosystem services is central to the design and implementation of economically efficient public policies that contribute to the sustainable use and conservation of ecosystems.

Table 2 shows the results of carbon sequestration and storage, both in biomass (organic matter that is generated from photosynthesis) and in soils (in the form of organic material that results from the microbial activity of the soil and development of herbaceous vegetation), whose total is 840,760 thousand tons, for the year 2014. Likewise, for that year, an estimated value of 279,553 million Mexican pesos (21,014 million USD[2]) is observed for the total carbon sequestration and storage service, considering a price of 25 dollars per ton of CO2, which translates into 1.67% with respect to the GDP of 2014.

[2] Average FIX exchange rate 2014: 1USD = 13.30 MXN

Table 2. Biomass living area and organic carbon in soils, 2014

Thousand tons, million Mexican pesos and as a percentage of the 2014 GDP

	Thousand tons			Million pesos			Percentage of GDP		
25 dollars SCC and 2% rate	Biomass	Soil	Total carbon	Biomass	Soil	Total carbon	Biomass	Soil	Total carbon
Storage	95,313	669,387	764,700	31,692	222,571	254,263	0.19	1.33	1.52
Sequestration	63,248	12,813	76,060	21,030	4,260	25,290	0.13	0.03	0.15
Storage + Sequestration	158,561	682,200	840,760	52,722	226,831	279,553	0.31	1.35	1.67

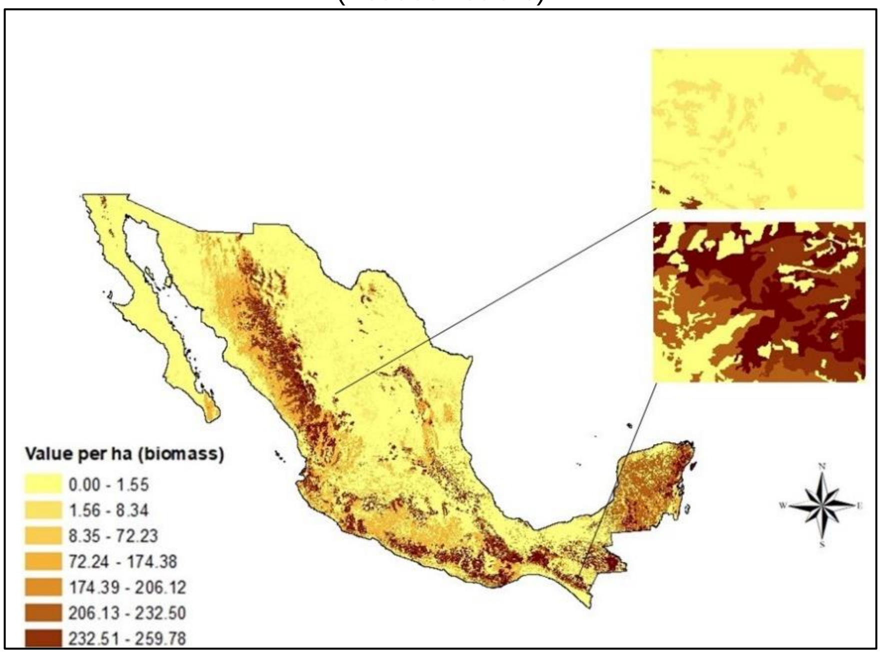
SCC: Social Cost of Carbon.

Source: INEGI 2021. Ecosystem Accounts of Mexico. NCAVES project´s results. INEGI. 168 p. Mexico.

Georeferenced, the monetary valuation shows a high value of carbon storage and sequestration, mainly in the south and west of Mexico, both in biomass and in soils. This shows the environmental and economic relevance of the ecosystems in that region and the importance of their preservation. (See Map 1 and Map 2).

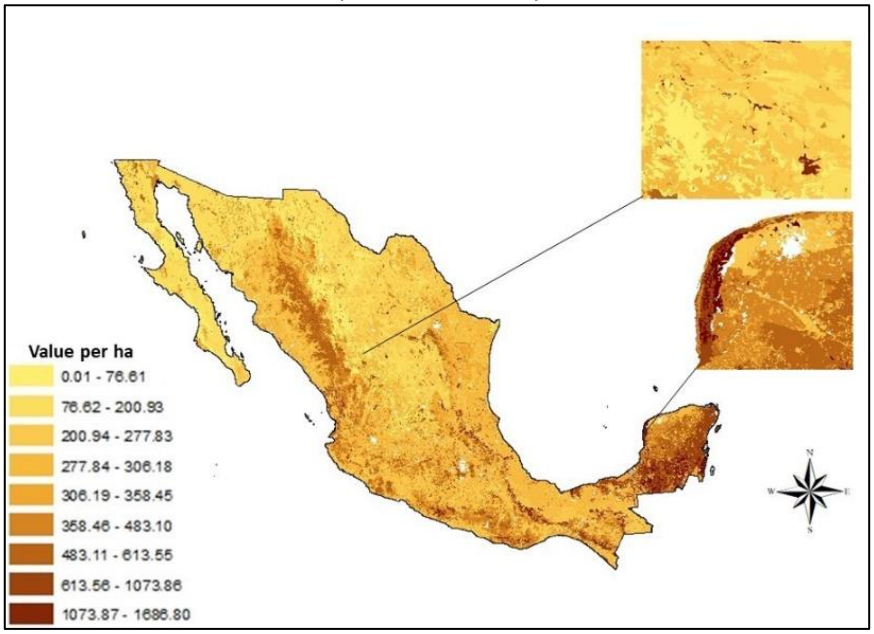
Map 1. Annual value of the carbon sequestration and storage services in biomass in Mexico, 2014
25 dollars SCC and 2% rate

(Pesos / hectare)



Source: INEGI 2021. Ecosystem Accounts of Mexico. NCAVES project´s results. Mexico.

Map 2. Annual value of the carbon sequestration and storage services in soils in Mexico, 2014
25 dollars SCC and 2% rate
(Pesos / hectare)



Source: INEGI 2021. Ecosystem Accounts of Mexico. NCAVES project´s results. Mexico.

Map 1 shows that the highest value of carbon sequestration and storage services in biomass was identified in the state of Chiapas, with an induced forest type of vegetation; on the contrary, the lowest value is found in the bushes of the state of Coahuila, in the north of the country. Map 2 depicts the annual value of the carbon sequestration and storage services in soils in Mexico highlighting that the soils in the state of Campeche (mainly Solonchak), have the highest carbon sequestration and storage value.

Estimating the monetary value of carbon storage and sequestration in forests and soils makes it possible to identify their contribution to mitigation processes and, therefore, to contribute to their incorporation into the strategies of the Predicted and Determined Contributions at the National Level (NDC) of the United Nations Framework Convention on Climate Change. On the other hand, the economic valuation of carbon will be an important element for the determination of the carbon tax that is globally included in the scenarios to meet the goals for abatement of climate change between now and 2030.

6. Examples of public policies to mitigate climate change using the measurement of carbon sequestration and storage in SEEA EA

The economic valuation of natural capital has the advantage to express the value of, or damages, of natural capital in the same terms as financial capital. In this sense, and as mentioned above, the economic valuation of carbon in SEEA EA, should be used as an important element for the determination of a carbon tax, which can provide general incentives to reduce energy use and switch to cleaner fuels used in economic activities, and therefore stimulate new investments in clean technologies (Parry, 2021). Therefore, this tax would also help to reduce the demand for goods and services that are carbon-intensive by increasing their prices and incentivizing efforts to make them less carbon-intensive, thus, helping to reduce emissions.

In accordance with a carbon tax, a public policy where a system of tradable permits is implemented for the reduction of carbon emissions limited by a cost to the most polluting industries, such as cement, electricity, oil and metallurgy, it would be essential to know the economic value of the carbon captured and contained in forests and jungles in order to trade such permits. Companies without permits would need to "buy compensation" for their emissions into the atmosphere, on the understanding that putting an expensive filter on the company costs more than maintaining a hectare of forest. The carbon valuation in the SEEA EA helps setting the costs of permits and compensations. For example, this price of carbon helps to set compensation mechanisms for an industry that cannot reduce emissions, so it chooses to buy forest in Mexico and a requirement is to know how much, in monetary terms, the carbon captured in our country costs.

The Marginal Abatement Cost Curves (MACC) of GHG estimate of the volume and costs of opportunities to reduce emissions in a given year. These MACC allow to set strategies in terms of cost-benefit analysis for the various economic activities that have the greatest impact on CO_2 emissions, indicating where investment is cheapest or which combination are most efficient. The value of carbon is thus a good reference to consider among the various possible mitigation actions, with their abatement potentials and costs. Moreover, revenues from these taxes can boost the economy and counteract the economic damage caused by rising prices for fossil fuels (Parry, 2021).

Since 2015, the Carbon Pricing Leadership Coalition (CPLC) works in this direction, providing a powerful platform to convene the private sector, governments, and civil society on carbon pricing to harness public-private collaboration to advance climate action and achieve sustainable development by seeking to expand the use of carbon pricing policies. The CPCL suggests a carbon pricing and a carbon trading system which works, although with some problems as individuals and industries tend to prefer to buy permits than to reduce their emissions. Nevertheless, as there is a finite number of permits that can be granted, in the future, their price will rise. So, it is imperative to know its value with respect to GDP. The monetary value of ecosystem services can be used in the cost-benefit or profitability of nature-based solutions to climate change.

In Mexico, this is particularly pertinent considering the relevance of emissions that come from the energy sector and changes in land use and agricultural activities. The carbon balance (flows and stocks) in any of these activities makes it possible to geographically define whether they are carbon sinks or emission sources, so it is important to have geospatial information for their mapping. The economic valuation of georeferenced carbon sinks allows the generation of indicators related to economic variables at the subnational level. The valuation makes it possible to link environmental information with macroeconomic variables for decision-making.

Below are some examples of public policies that can be addressed from the data of the destination of the emissions:

- Nationally Determined Contributions (NDC). They identify the relevant information for the implementation of the Paris Agreement and make visible the relevance of ecosystem services in adaptation commitments. Ecosystem accounts provide data and accounting tables on carbon sequestration and storage and imputing geospatial information to generate carbon maps in soil and biomass at the national and local levels. Additionally, this can be accounted in an economic way.
- Carbon taxes. The carbon sequestration and storage data allow geographically locating the large sinks in forests and jungles, as well as the economic values of the service, so it is important to have geospatial and economic information on a recurring basis for their construction. Carbon taxes in Mexico are already considered in the Federal Environmental Responsibility Law, Sustainable Forest Development Law, General Climate Change Law and in the Law of Special Tax on Production and Services. It is based on the quotations of the average price of a ton of CO_2 in the carbon credit markets, so that its calculation could benefit from specific information on the contribution by the types of ecosystems to their mitigation.

- Mexico´s National Strategy for the Reduction of Emissions from Deforestation and Forest Degradation was established as a priority strategy of the National Forestry Program (PRONAFOR) to "move towards a zero rate of net deforestation and [promote] the capacity to adapt to the effects of climate change" (DOF -Official Gazette- 2020e). In this sense, it is important to have national and sub-national information on the sources of emission and destination of CO_2 that allow establishing local and national strategies, which is why the geospatial and economic information of the Mexico Ecosystem Accounts project is of great relevance. The economic benefits of forest ecosystem services provide a baseline for REDD decision making in relation to co-benefits and opportunity costs.
- The Payment Program for Environmental Services has been implemented in Mexico since 2003 by the National Forestry Commission and is currently incorporated into the Support Program for Sustainable Forestry Development. Until 2017, the area benefited by this program was 2.68 million hectares (SEMARNAT, 2019). The values per ton of carbon can be considered for the determination of the compensation payment. For this purpose, it is important to have statistical and geographic information with a high level of granularity, at least at the municipality level, in order to help strengthen the strategy of payment for environmental service by ecosystem type.
- The social cost of carbon (SCC) is an estimate, in monetary terms, of the economic damages that would result from emitting one additional ton of GHG into the atmosphere. The SCC puts the effects of climate change into economic terms to help policymakers and other decisionmakers to understand the economic impacts of decisions that would increase or decrease emissions. From the point of view of public policy, it can be included in cost-benefit analysis that make it possible to determine the economic viability of a specific project. The efficient implementation of these public policies requires knowing their economic costs and benefits, which entails having an estimate of the economic, social and environmental cost caused by the negative externality of CC. Thus, the concept of the SCC is central to the economics of CC.

7. Conclusions

The environmental, economic and financial sectors, as well as their interrelations, will face important challenges with CC. This represents both a challenge and an opportunity for the integration and generation of statistical and geospatial information that may be useful for these sectors. The specific needs of certain economic activities will require relevant information to take care of the fixed assets of the companies that face risks and their sensitivity to such risks. This will put pressure on the mechanisms for assuring the quality of these data, models and information. Risks will have to be valued at market prices so that companies consider this in their decision-making processes and, thus, evaluate their decisions and actions taken. All this must be done in a state of transition towards a more sustainable economy.

The mitigation and adaptation efforts in general, and in particular of the financial and economic sectors, will require financing and this in turn will require regular, timely and quality information in terms of adaptation and mitigation to CC, such as the inventory of GHG emissions. The ecosystem accounts will be a fundamental basis to support and monitor public policies related to CC.

Moreover, knowing the global carbon cycle is essential to guide efforts on a more concrete basis. Knowing the origin and destination of emissions allows a more complete picture of the phenomenon and can support, in a specific way, informed decisions. For example, it is very useful to know which sectors generate the most pollution, how much carbon is absorbed by the sea, forests, soil, etc. For this purpose, it is important to consider the use of geospatial information, which from the accounting framework of the SEEA EA allows to generate accounts of ecosystem services, such as provisioning, regulation, and even aesthetics and tourism. In this context, the services related to carbon sequestration and storage are georeferenced at the national and local level, both in tons and in monetary values.

The accounting scheme of the SEEA EA helps us to know part of the destination of these emissions (through the accounting balance of carbon in soil and biomass), with focus on carbon storage and sequestration ecosystem services. But if we also assign an economic value to these services, it would allow us to measure more adequately their size and importance. In addition, with the SEEA EA, through the carbon balance we know how much is absorbed by forests or the sea and therefore, inferences can be made about how much is left in the atmosphere. Hence, it is worthwhile to continue conserving ecosystems, protected natural areas, and direct more efforts towards social issues such as agricultural subsidies, which can help mitigate the impact of climate change.

The results of projects such as the SEEA EA, where the ecological and economic visions are combined, are expected to have a direct impact on the design and application of public policies, or on the improvement of existing ones. When these accounts are combined with the power offered by technologies and geospatial information, which makes it possible to know precisely the territory and ecosystems, a powerful tool is generated that allows defining specific actions and has vast analytical applications. An example of them is the payment for environmental services where, on the one hand, select ecosystems have been benefited, but vulnerable ecosystems have been left unprotected.

With this dual approach, it is possible to generate more specific and complementary inputs for decision makers on public policy related to CC. For this purpose, it is important to take advantage of the current availability of geospatial tools that help to locate the origin and destination of atmospheric carbon emissions, identifying the cycle that follows from their emission sources, sequestration by sinks, and concentration in the atmosphere. Likewise, by incorporating principles of national accounting, it is possible to work on the development of tables of origin and destination of emissions. An additional issue that should be highlighted is the importance of granular statistical and geospatial information at the national and local levels since the effect of public policies have different effectiveness as they are implemented at sub-national levels. The NCAVES Project in Mexico, incorporated the measurement of carbon balances, separately identifying carbon sequestration from storage, being the only country that has estimated the valuation of the carbon storage and sequestration service so far, of the five countries in which the NCAVES pilot project was developed.

The georeferencing of the carbon sequestration and storage information at the national and local levels, and the assignment of an economic valuation for the services provided by the ecosystems, through the SEEA EA, demonstrates the importance of having geospatial information and its integration with statistics to support decision-making in matters of national and global policies, which seek to mitigate the phenomenon of CC and promote a sustainable development.

A challenge of this approach is that the experts who prepare the macroeconomic statistics of a nation may not be familiar with the complex world of geospatial information, so in order to be able to exploit the benefits and power of georeferenced statistical information, they need to learn about it and acquire the capabilities to integrate data of a very different nature: GDP, remote images over time, types of soil and vegetation, big data, etc. These data must be curated in a coherent framework, to make it possible to extract knowledge that serves as an input for sound decision-making processes based on objective evidence.

8. References

Buckley, E. 2021. Climate cooperation. Working with members, the IMF is managing the risks and opportunities of Climate Change. Finance and Development 58 (3). September. pp: 26-27.
Camill, P. 2010. Global change: an overview. Nature Education Knowledge 3:53-57

Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO). 2021. Ecosistemas-servicios ambientales (https://www.biodiversidad.gob.mx/ecosistemas). Reviewed in August 2021.

Dasgupta, P. 2021. Economics nature´s way. Good economics demands that we manage nature better. Finance and development 58 (3),16:19

Del Ángel-Mobarak, G. 2012. La Comisión Nacional Forestal en la historia y el futuro de la política forestal en México. CONAFOR-CIDE. ISBN 9786077843191. 338 P.

Environmental Protection Agency (EPA). 2021. Green Power Partnership Leadership Award. Consulted and available in: https://www.epa.gov/greenpower.

Instituto Nacional de Ecología y Cambio Climático. Inventario Nacional de Emisiones de Gases y Compuestos de Efecto Invernadero. https://www.gob.mx/inecc/acciones-y-programas/inventario-nacional-de-emisiones-de-gases-y-compuestos-de-efecto-invernadero. May 2018.

Parry, I. 2021. Five things to know about Carbon pricing: Carbon pricing shows promise as a tool in the fight against climate change. Finance and Development 58:10-11.

Román-Palacios, C.,and J.J. Wiens. 2020. Recent responses to climate change reveal the drivers of species extinction and survival. PNAS: Doi: https://doi.org/10.1073/pnas.1913007117. Reviewed in September 2021.

Sauvé, S., S. Bernard, P. Sloan. 2015. Environmental sciences, sustainable development and circular economy: alternative concepts for trans-disciplinary research. Environmental development 17: 48-56.

Tilman, G.D., N. Hartline, and M.A. Clarck. 2019. Twenty-eight: saving biodiversity in the era of human-dominated ecosystems. In: Lovejoy T.E. and L. Hanna (eds). Biodiversity and climate change: transforming the biosphere. Yale University Press. 416 P.

United Nations (2021). BIOFIN, the biodiversity finance initiative. Consulted and available in: https://www.biofin.org/sites/default/files/content/publications/biofin_brochure_sp_april 5.pdf.

United Nations. Department of Economic and Social Affairs. Statistics Division. SEEA Experimental Ecosystem Accounting Technical Committee under the auspices of the UN Committee of Experts on Environmental-Economic Accounting (UNCEEA). System of Environmental-Economic Accounting—Ecosystem Accounting. Final Draft. 2021. https://unstats.un.org/unsd/statcom/52nd-session/documents/BG-3f-SEEA-EA_Final_draft-E.pdf. Reviewed in September 2021.

Villers, L. e I. Trejo. 1998. Impacto del cambio climático en los bosques y Áreas Naturales Protegidas de México. Interciencia 23:10-19.

Villers, L., N. Arizpe, R. Orellana, and C. Conde. 2009. Impacts of climate change on coffee flowering and fruit development in Veracruz, México. Interciencia 34: 322-329.

Vitousek, P. 1992. Global environmental change: an introduction. *Annu. Rev. Ecol. Syst*. 23: 1-14.

Weiskoff, S., M.A. Rubenstein, L.G. Crozier, S. Gaichas, R. Griffis, J.E. Halofsky, K.J.W. Hyde, T.L. Morelly, J.T. Morisette, R.C. Muñoz, A.J. Pershing, D.L. Peterson, R.P. Michelle, D.S. Ariana, E. Sutton-Grier, L. Thompson, J. Vose, J.F. Weltzin, and P. Whyte. 2020. Climate change effects on biodiversity, ecosystems, ecosystem services. And natural resources management in the United States. Sci. on the Tot. Env. 733: 1377-1382. Doi. https://doi.org/10.1016/j.scitotenv.2020.137782.