Clean Energy and Water: Assessment of Mexico for improved water services with renewable energy

By

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2011

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Executive Summary

Mexico is a diverse nation with an estimated population of over 113 million people. Vast natural resources and strained water supplies make Mexico an interesting setting for studying the energy-water nexus. Despite its energy status as a major oil producing country, Mexico struggles with water stress with nearly all of its land area experiencing or approaching physical water scarcity.

With over 11 million people lacking access to water supplies and 22 million lacking access to sanitation, there is a pressing need for development of the water sector in both rural and urban settings. Solving much of Mexico's water issues requires energy for extracting, transporting, and treating water where it is needed most. Yet such energy use is not always possible since 3 million people are not connected to an electricity grid. Consequently, there is an opportunity to improve water services through use of distributed renewable energy technologies.

Various policies and technologies are relevant to the energy-water nexus on a decentralized scale. In particular, distributed rainwater collection and solar hot water heating are effective technologies that deliver water services solely from renewable energy, directly offsetting use of primary fuels or fossil fuel-generated electricity. Additionally, policy levers such as mandates and right-pricing of water and energy can help encourage sustainable operation of established water and energy systems.

The efficacy of integrating renewable energy and water systems is demonstrated through case studies of northern Mexico and the Mexico City Metropolitan area. Particularly important factors for technology development include consideration of performance parameters, cultural acceptance, willingness to pay, and financing. Based on this analysis, we deduce the following key findings:

- Solar hot water heating can reduce fuel use when appropriately implemented.
- Affordable financing is essential for technology adoption.
- Understanding a customer's ability and willingness to pay is important.
- Fresh ideas for water and energy conservation can make large strides towards mitigating the acute challenges at the energy-water nexus.
- Information communication technology (ICT) can be an effective means of education.

Further research is necessary to pinpoint the most appropriate policies and technologies for integrating renewable energy and water services. Current results reveal great potential for improving water services in Mexico through use of renewable solar energy technology.

In response to our key findings, we propose the following recommended areas for investment in future research:

- *Willingness to pay for water and wastewater services*

  Many people that currently lack adequate water and wastewater services – including the poor – might be willing to pay for improvements and/or new installations. Understanding the percentage of household income spent on water and wastewater services can help determine a population's willingness to pay for adequate service. Conducting local surveys to gather information on existing levels of water and wastewater service, desired service, and willingness and ability to pay could greatly inform policy and management decisions.

- *Using renewable energy and ICT to facilitate participatory networks for water resources management*

  Placing the costs for renewable energy technologies and ICT in the context of the distribution of household expenses and government budgets could help facilitate technology adoption. Furthermore, integrating renewable energy with ICT can aid data collection and decision-making. ICTs enable objective data collection and presentation that can facilitate participatory networks that bring stakeholders together to best provide water services for disparate needs such as potable municipal water, irrigation, and aquifer maintenance and protection. Because water-related issues are specific for each geographic location, research into how to best collect and present accurate information on water use and resources is always an opportunity.

- *Economic analyses of coupling renewable energy with water services*

  Analyzing the economics of coupling renewable technologies with water services in the context of a local environment is important for overall feasibility. Non-monetary factors, such as aversion to a particular technology, might influence the adoption of certain technologies. Consequently, targeted economic analyses are necessary to determine appropriate subsidies or incentives to encourage adoption.

- *Statistical analyses of project success in terms of technical complexity*

  Installing technically complex water or energy solutions in rural communities can be an unsustainable practice when the technology is poorly understood. A statistical analysis of the technical complexity of a solution and the length of time it operates would help convey how well technology can be maintained by rural communities. This sort of analysis could reveal the ramifications of installing distributed renewable, high-technological solutions in areas without experienced people for repairs and maintenance or quick access to replacement parts.

- *Role of microfinancing*

  Understanding the importance of collective group loans to overcome up-front costs for water infrastructure and renewable energy installations (such as photovoltaics or solar water heating) is important for distributed technologies. Studies could determine the ability of microloans to maintain sufficient pervious cover regions and groundwater recharge zones and maintain wetlands that provide ecosystem services related to water filtration and aquatic habitat. The Nature Conservancy pilot study in Quito, Ecuador, could be used as a guide for Mexico City or areas that need water recharge.

- *Understanding discretionary spending for different cultures*

  The level of discretionary spending amongst a particular population can reveal how spending is allocated toward basic needs. Relating household total income/expense level and GDP (or GDP per capita) could lead to a better understanding of appropriate pricing for water and energy services, along with suitable investments in renewable energy technologies. Results from such research could assess discretionary income (approximately total income minus spending for water, transportation and/or liquid fuels, food, and electricity) to investigate the human development pattern associated with general income and reliable and clean water service.

Filling these research needs is possible via additional primary research and development interventions. Integrated scientific and sociological research could help advance the sustainability of implementation of renewable energy technologies for water supplies. Development interventions can aid project implementation when economic factors pose a major obstacle to technology adoption. Fully understanding the roles of research and investment can increase the likelihood of successfully integrating renewable energy technologies with water supplies.

Introduction

In both developed and developing countries, many people lack access to drinking water and sanitation. A multitude of factors influence the ability to access water systems: remote villages can be difficult to connect to centralized water distribution networks; local water supplies can be contaminated and require energy-intensive treatment to make the water of sufficient quality for drinking; and resource over-exploitation can leave little to no local water available to supply growing populations. Solving many of these water supply challenges requires energy. Unfortunately, often the areas that lack access to water are the same areas that lack access to electricity. Thus, due to the nexus of energy and water, some people do not have access to quality water due to energy limitations for water treatment and/or distribution.

Fortunately, renewable energy technologies can couple with water systems to provide water access and other water-related services to various populations. Water systems linked with renewable energy technologies can be appropriate for both rural and urban populations, depending on different resource factors. Integrating the two resources can also alleviate strain on the energy-water nexus, preserving water and energy for the future. This analysis focuses on the nation of Mexico and unique applications of renewable energy-supported water systems.

In the framework of the Climate Change and Water (CCW) programme initiative of the International Development Research Centre (IDRC), this report is part of an exploratory project that was recently launched aiming to address, through a number of assessment reports, case studies, and a workshop, some key knowledge gaps in the use of renewable energy technologies for water services in developing countries. The goal of the programme is to analyze the way energy and water services can be combined and improved to enhance resilience and adaptive capacity of communities to climate variability and change, and to enable equitable access to and robustness of those services under growing conditions of uncertainty. Focus is put on the socioeconomic, environmental, and policy implications of different decentralized technological choices.

The objective of this report is to assess the potential of – and barriers to – the use of decentralized renewable energy technologies for water services in Mexico with consideration for impacts from climatic stress. In this way there will be information to help communities in Mexico better adapt to climate change and increasing uncertainty on their availability of water resources.

Specific objectives of this report are:

Objective 1: To foster and support the development of knowledge to explain when and why decentralized renewable energy technologies for water services are not used; and to help understand what could happen if they were used more extensively, in particular in areas under climatic stress or risk.

Objective 2: To determine the challenges and opportunities for research to inform policies and initiatives aiming to enhance the climate change adaptation capacity of people living in areas under climate-related water stress.

Objective 3: To formalize the results related to Objectives 1 and 2 and to communicate those results in an international workshop to be organized and sponsored by IDRC.

Objective 4: To define clear and practical entry points for further investment and research support by the CCW program initiative of IDRC.

This report is meant to give a general analysis of knowledge gaps in planning for water, but it also contains examples, information, and rationale for specific future research, and information on the strategic actors and stakeholders who could be involved in the proposed future work.

Chapter 1. Mexico in the context of the energy-water nexus

With an estimated population of over 113 million people and diverse natural resources, Mexico is an interesting nation in terms of the energy-water nexus. Mexico is an energy-rich nation: the seventh largest producer of oil in the world in 2009 [1], and the twentieth largest consumer of electricity [2]. On the other hand, Mexico is a water-stressed nation: most of the land area is classified as experiencing or approaching physical water scarcity [3]. In 2005, 89.8% of the population had access to drinking water – measured as persons with piped water to their property or access to a public source – leaving over 11 million without such access [4]. At the same time, 77.6% of population had access to sanitation – measured as persons connected to a sewer or septic tank system and those discharging directly to a river, lake, or ravine – leaving over 22 million without such access [4]. Inadequate or non-existent water and sanitation systems are usually found in rural areas, but some urban areas are also lagging in water infrastructure development.

Diverse natural resources, however, represent promising possibilities for a sustainable future in Mexico. Opportunities exist to harness renewable energy sources and develop and sustainably maintain water supplies. Targeted policies and an understanding of the interrelationship between energy and water can help facilitate such developments.

The following general discussion and maps are intended to serve as background on the geography and natural resources of Mexico. This background is later used to provide context for specific case studies focused on the energy-water nexus in Chapter 3.

1. Climate and natural water resources in Mexico

Mexico's geography is characterized by a chain of mountains and high plateaus in the interior with flat plains near the coasts, as shown in Figure 1. Mexico City, both the capital and largest city, is a densely-populated urban core located in the central area of high plateaus. Clusters of high population density are located in the central plateau area, some coastal areas, and cities near the United States-Mexico border, as shown in Figure 2. Opportunities exist for sustainable development of both renewable energy and water resources in the plains and plateaus, both urban and rural.

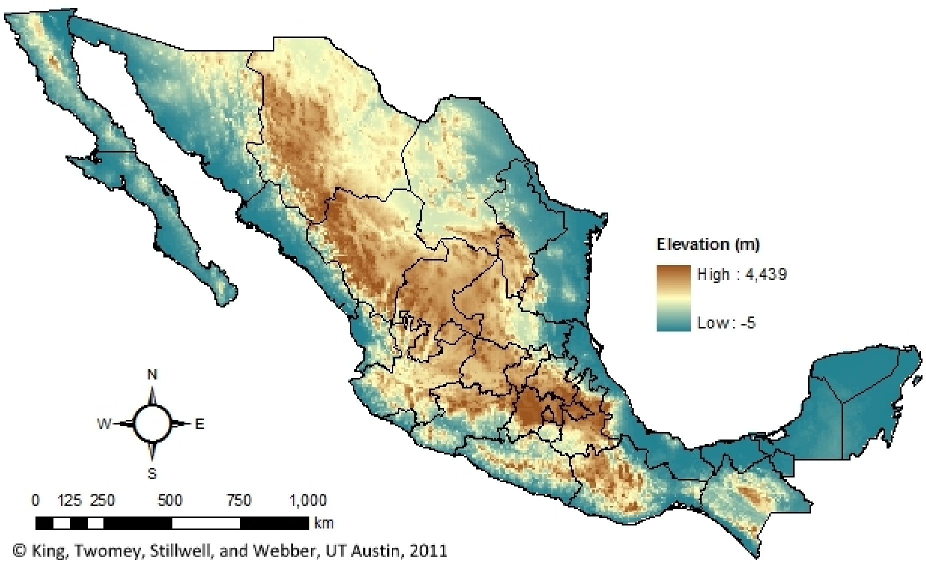

Figure 1. Elevation topography of Mexico (map created based on data from [5]).

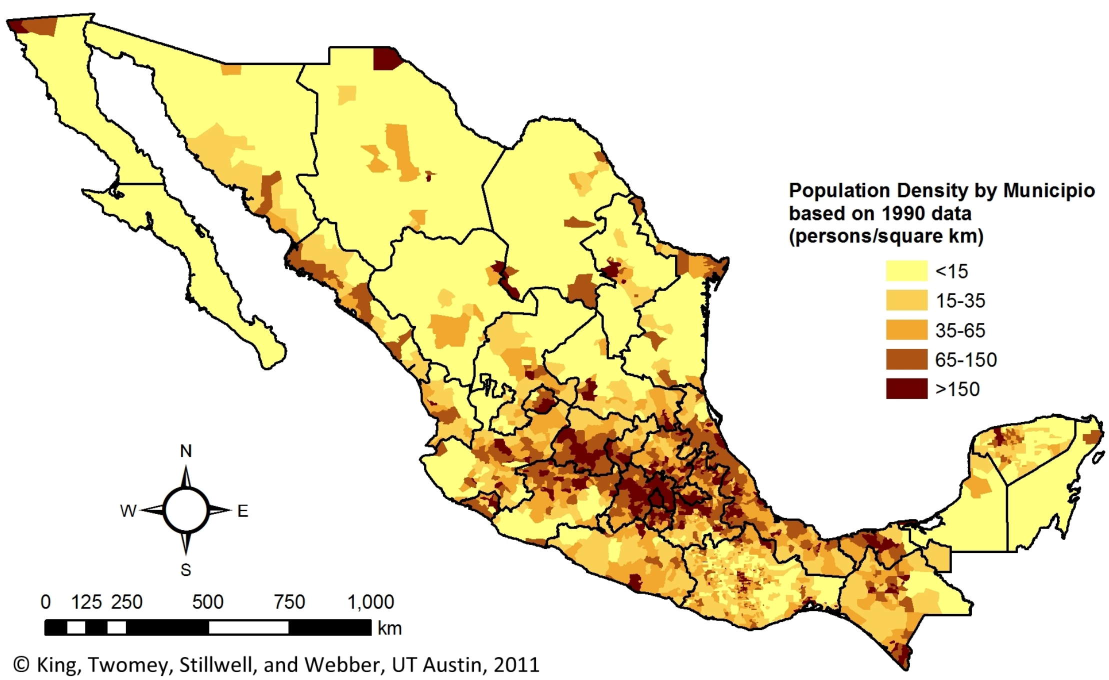

Figure 2. Population density of Mexico (map created based on data from [6]).

1.1. Natural and fresh water resources and use

The annual renewable supply of freshwater in Mexico is 450 billion m^3, which is sufficient to support the population based on per capita water needs. However, this supply is unequally distributed. While the Northern and Central Regions are relatively dry with 28% of the total water, they also represent 92% of Mexico's irrigated land. Irrigated land area covers 9 million hectares (29% of total agricultural area), but represents over half of agricultural production [7]. Annual precipitation is high in the southeast, as shown in Figure 3, making the area characteristically wet with ample surface water supplies in rivers (Figure 4) and lakes (Figure 5).

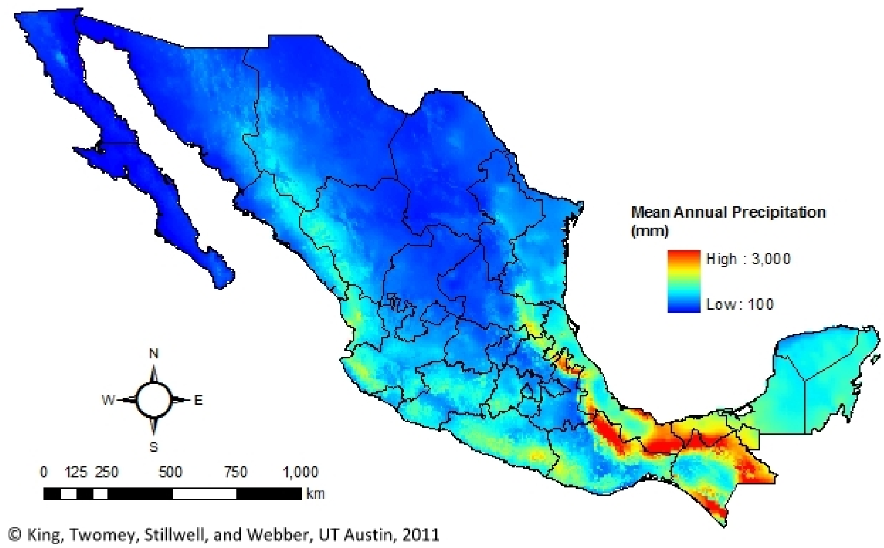

Figure 3. Current mean annual precipitation (mm) across Mexico (map created based on data from [8]).

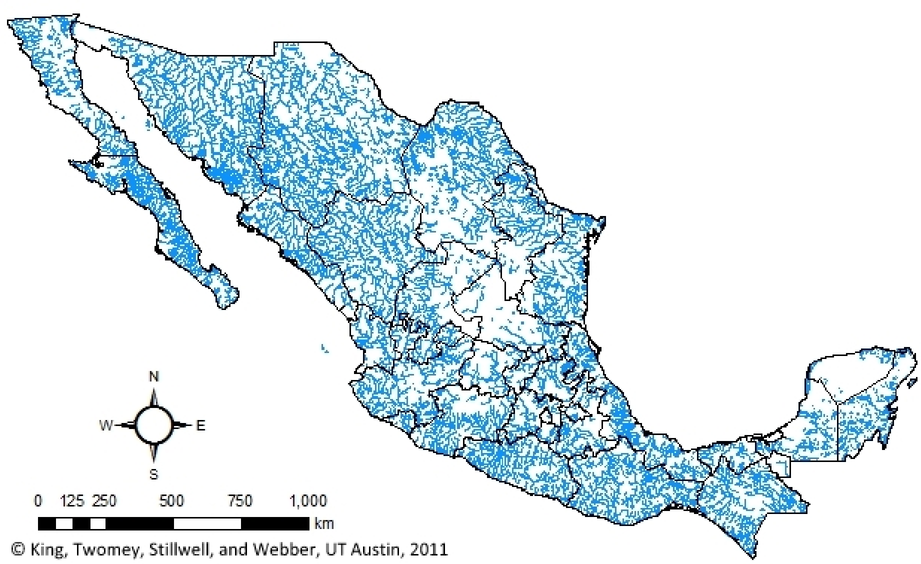

Figure 4. Rivers and streams of Mexico (map created based on data from [5]).

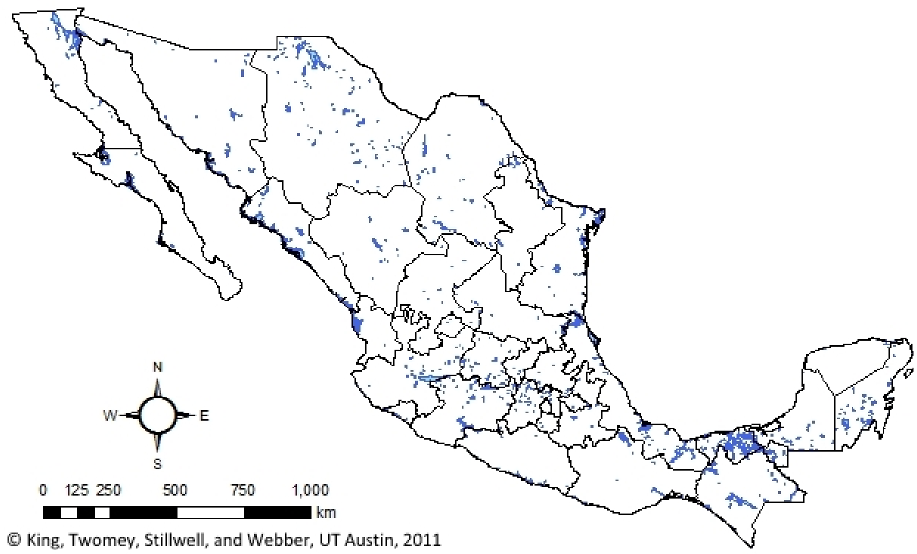

Figure 5. Inland water bodies (lakes and permanently inundated land) of Mexico (map created based on data from **[5]**).

In many areas where groundwater is used extensively, water extractions often exceed renewable supplies leading to unsustainable depletion. Groundwater depletions are highest in the northern regions, which contain the majority of Mexico's industries, but only 20% of its precipitation.[9] These water extractions have increased over time. In 1975, 32 of 202 measured aquifers were considered over-exploited; the number increased to over 100 by 2005. This total is likely understated, since 451 aquifers are not monitored [7].

1.2. Water resources management and policy in Mexico

Numerous policy measures govern the management of water resources in Mexico. Article 27 of the 1917 Constitution of Mexico, amended September 2, 2004, requires the government to protect the environment and regulate the distribution of water. Some of its regulatory responsibilities include overseeing the extraction and utilization of groundwater, concessions, riparian rights, national reserves, and communal possession of water rights. The federal government also establishes government bodies for dealing with water issues [10].

National Water Act

The National Water Act of December 1993 (amended in 2004) governs water management of both surface water and groundwater. Under the Act, the federal Government must approve a national water program that integrates specific regional, basin, state, and sectoral subprograms [10]. Additional requirements mandate the creation and upkeep of the *National Registry of Water Rights*, the formulation of strategies and policies for regulating water use, the implementation of water use programs that involve all relevant users and their organizations, and designation of well levels that are based on the natural replenishment levels of water [9, 10].

Article 7 identifies water-related matters that are deemed to be in the public interest and includes 1) the protection, conservation, and enhancement of basins, aquifers, river beds, enclosed bodies of water, and other nationally owned water bodies; 2) the use of water for hydroelectricity; 3) restoring the hydrological balance between surface and groundwater; 4) the construction of wastewater treatment facilities; and 5) the construction, operation, maintenance, and development of public waterworks. Organismos de Cuenca (Basin Organizations) are state-level organizations created by the federal government (also under Article 7 of the National Water Act) to resolve water-related conflicts [10].

Like most countries, water management policy is not confined to the National Water Act alone. Other pertinent laws include the 1971 Law of Prevention and Control of Pollution, 1982 Law for Protection of the Environment, 1988 General Law on Ecological Equilibrium and Environmental Protection, 1992 Federal Law of the Sea, and 1992 Fishery Law. These policies interact to govern water resources throughout Mexico.

Rights to water

Water resources in Mexico are generally considered "national water" – waters that are owned by the nation under Article 27(5) of the Constitution of Mexico [10]. Although water was historically controlled by the agrarian community, this shift towards centralized regulation by the federal government in the late 1980's marked a transition in the Mexican economy towards non-agrarian resource water and energy demands.[9] Under national water ownership, individuals and corporations must be granted the right to use national waters by obtaining a concession from the National Water Commission, Comision Nacional del Agua (CAN), through the Organismos de Cuenca in accordance with the rules and procedures defined in the Water Act (Water Act, Article 20). State and municipal departments or agencies and federal agencies can obtain the right to use water through a grant from the Commission (Water Act, Article 20). Additionally, any legal or naturalized individual can apply for a concession by submitting an application to the CAN in order to enter a competitive bidding process to obtain a water-use concession [10]. The application must detail the location where water is to be withdrawn, the amount of water to be consumed, the use of water, the period for which the concession is sought (between 5 and 30 years), and the waterworks, if any, that will be constructed. Granted concessions are overseen and enforced by state-level Aquifer Management Councils [9]. All granted concessions are recorded in the *National Registry of Water Rights*. The registry also documents final decisions of judicial and administrative tribunals concerning disputes of concessions, grants, and regulated zones and their status (Water Act, Article 30) [10].

Users have a right to use national water for agriculture, fish farming, tourism, and other productive activities, provided that the user has obtained a concession from the Commission in coordination with Mexico's Secretaria de Agricultura, Ganaderia, Desarrollo Rural, Pesca y Alimentacion (SAGARPA; Secretary of Agriculture) (Water Act, Article 82). Surface water can be freely used "by manual means" for residential and stock-raising purposes, as long as there are no significant changes in the flow of the water or in its quality or quantity. Groundwater can be freely extracted by artificial works unless the federal government regulates water extraction and utilization in the interest of the public [10].

Water rights are considered personal property and can be transferred or cancelled. Concession transfers must be approved by the Commission and incorporated into the Registry. Rights to water are suspended if the concession holder or grantee fails to make required payments, refuses to allow required inspections, discharges wastewater, does not comply with the terms of the concession or grant, or harms. Additionally, water rights are cancelled if the concession holder dies, renounces his concession, or fails to use the granted concession for a period of two consecutive years; the competent authority deems the concession or grant invalid; or the period of the concession expires [10].

Water infrastructure

Separate from water rights, water infrastructure is also regulated by various authorities. A concession can authorize the construction (by both public and private entities) of waterworks projects. The federal Executive Branch decides if hydroelectric facilities will be built by the National Water Commission or the Federal Electricity Commission (FEC), in which case both the Commission and FEC cooperate in administering infrastructure [10]. *This coordination between the Commission and FEC is an example of governmental conjunctive management of both energy and water.*

In terms of infrastructure and management, the Director General of the Commission (under the Secretariat of the Environment and Natural Resources), is appointed by the Federal Executive, and is responsible for building and operating the federal water infrastructure needed to protect, conserve, and improve water quality in watersheds and aquifers. Additional responsibilities include the authority to formulate, revise, and oversee the implementation of the national water plan to promote the development of water supply and sewer systems; safeguarding national water resources, including their quality, issuing concessions, grants, and permits, promoting the efficient use of water; concluding agreements with foreign organizations or institutions and compatible organizations in order to attain technical cooperation; updating and periodically publishing the inventory of national waters; integrating into the National Information System the quantity, quality, uses, and conservation of the water; and monitoring compliance with the Water Act [10]. The Commission is responsible for administering national properties that are adjacent to national waters, including the water-related infrastructure on such land; coordinating with state and municipal governments, individuals, and corporations on flood prevention activities; and collaborating with the Federal Electricity Commission in developing the program for water that can be used for hydroelectric purposes.

Agriculture and water

Agriculture plays a major role in Mexican water resources management and policy. Seventy one percent of Mexican land devoted to crop production in 2002 was rain-fed. Although only 29% of the remaining crops were irrigated, these irrigated crops account for 55% of total agricultural production and 70% of total agricultural exports [7]. Accordingly, irrigation water for agriculture is important for economic well-being. But this irrigation water use can also be harmful in terms of water quantity and quality. In total, 60% of Mexico's water consumption is for irrigation, 90% of which is done in dry or semi-arid regions.[9]. The average efficiency of agricultural water use is as low as 43% since water and electricity subsidies incentivize water exploitation, and consequently, irrigators have very little economic incentive to monitor the proper operation of their irrigation systems [7, 9]. Water pollution is mainly caused by irrigation through chemical runoff, but livestock effluent is becoming an increasing factor [7].

Agriculture policies have both positive and negative effects on national water resources. Market price support for agricultural commodities instituted in 1990s managed resource exploitation in comparison to prior schemes that incentivized over-production [7]. However, the majority of land is owned by the community, which leads to the "tragedy of the commons"[2] with resource exploitation. Since no individual is held responsible, it is difficult to implement resource management policies or reprimand bad behavior.[11] *Additionally, lack of data hinders the ability to monitor the status of water resources.* Less than one-third of 653 aquifers have been studied, making identification of resource depletion or contamination challenging. Water use subsidies, as exemption from fees or subsidies for the energy needed for irrigation, encourage over-use or misuse of water [7].

Agriculture also has a large effect on water right concessions, as it accounts for three-fourths (by volume) of total concessions. In the Northern and Central regions, concessions often amount to over half of water availability, whereas little water is assigned to concessions in the more South. Of these agricultural water concessions, two-thirds are tied to surface water and one-third to groundwater [7]. Concessions are not well-enforced, and often exceed the allotted volume permitted. Over-extraction is often committed by smaller concession holders, though scale is usually correlated with agricultural activity since scattered, small-scale users are harder to police than large users. Often the administrative burden of enforcing concessions and collecting payments is large and costly. Applications to obtain new concessions, therefore, are often backlogged over multiple years, which promotes illegal extraction of water by those that need it.[9]

Allocation of agricultural water reflects subsidies received, not the economic value of the crop. For example, high-value agricultural commodities get 10% of the water for agriculture, while low-value commodities, such as cereals, are highly irrigated. In 2003, an important policy was enacted to remove farmers' exemption for water charges, which was intended to reduce water waste and misuse. However, water subsidies are concentrated in the economically rich north, so such policies are ineffective for alleviating poverty [7]. Overall, the lack of data makes full evaluation of agricultural policies' impact on water resources difficult.

Based on the current state of agriculture and water use in Mexico, the Organisation for Economic Cooperation and Development (OECD) issued a set of recommendations for sustainable agricultural water use. These recommendations include measuring water resource use and enforcing private and public property rights; adopting "polluter pays" and "user pays" principles, which Mexico has yet to fully implement; improving measurement of resource use and enforcing

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[2] The "tragedy of the commons" refers to a concept of environmental risk induced by shared (or common) land for which there is no single property owner or regulatory authority to oversee its sustainable management. The idea was published by Garrett Hardin in *Science*, December 13, 1968.[11] Hardin, G., *The Tragedy of the Commons.* Science, 1968. **162**: p. 1243–1248.

property rights; encouraging water user associations; and distributing water meters to farmers exploiting private wells to foster sustainable use [7]. The OECD recommendations also focused on identifying the inadvertent consequences of other government policies on water resource use such as 1) poor management of communal lands, 2) policies encouraging production that also encourage over-exploitation of natural resources, and 3) expansion of irrigation systems that encourage excessive water use.

1.3. Sanitation and decentralized wastewater treatment

Wastewater treatment as a human sanitation measure requires energy for collection and treatment of sewage. This energy requirement is often larger than the energy required for collection, treatment, and distribution of drinking water when local sources are used. That wastewater needs more energy than water is true in the case of Mexico City since all wastewater must be pumped out of the city due to the fact that the city is sinking and systems once driven by gravity now require large amounts of electricity.[12] Centralized wastewater treatment plants tend to exhibit economies of scale with larger facilities consuming less energy per volume of wastewater treated than smaller facilities. Similarly, centralized wastewater treatment plants consume less energy per volume of wastewater treated than their decentralized counterparts. Furthermore, energy and nutrient recovery is best suited for the centralized wastewater treatment scale due to the higher concentrations of organic content in the inflow [13, 14].

Centralized wastewater treatment, however, does not solve all sanitation problems. While 77.6% of population of Mexico has access to sanitation, over 22 million people lack such access [4]. Improper access to sanitation is focused in rural areas where large investments in centralized infrastructure are not justified due to the amount of energy required to pump sewage long distances. *Consequently, distributed wastewater treatment technologies are likely appropriate to meet rural sanitation needs in Mexico.*

Regardless of the energy benefits, massive infrastructure investments can be a burden for installation of centralized wastewater treatment in areas without existing sanitation. In response, many communities install decentralized, distributed wastewater treatment technologies, such as septic tanks, package treatment systems, and membrane bioreactors (MBRs) [14]. Package treatment systems perform many of the same operations as centralized treatment facilities on a smaller scale and could be suitable for some areas of Mexico. MBRs use membrane technology to facilitate digestion of organic contaminants in wastewater and separate solids from cleaner effluent in a compact unit operation. These small-scale wastewater treatment technologies are well-suited for remote locations and areas where constructing sewer mains connecting to a centralized facility is economically infeasible, yet require electricity for operations.

Energy and nutrient recovery is possible on a distributed scale using heat recovery and microbial fuel cells (MFCs), among other technologies [13, 15]. While wastewater contains low-grade heat, heat recovered using a heat exchanger or heat pump can be used for local household heating or cooling and is up to 1.5 times more efficient in colder months than using outside air [16]. Use of MFCs generates electrical energy via oxidation-reduction reactions on a biofilm surface that simultaneously cleans wastewater and produces less sludge than similarly sized activated sludge treatment units, though operation and control of MFCs can be challenging [15].

Source separation – separating various waste streams at the source of generation – is important for feasible energy and nutrient recovery with distributed wastewater treatment technologies [13]. While distributed wastewater treatment is not preferred from an energy standpoint, energy and nutrient recovery is still possible with decentralized wastewater technologies and can help offset much of the energy consumption of the treatment process. Implementing such sophisticated wastewater systems, however, can encounter cultural resistance due to lack of familiarity with the technology.

2. Energy resources in Mexico

2.1. Petroleum production in Mexico

Mexico was the seventh largest producer of oil in the world in 2009. Consequently, revenues from oil are extremely important to the country's economy. Crude oil constitutes about 72% of Mexican energy production, followed by natural gas, which represents 17%. The remainder of production is comprised of a small percentage of combustible renewables and waste (4%), non-combustible renewables (i.e. geothermal and solar, 3%), nuclear (1%), hydroelectricity (1%) and coal (1%) (based on the energy content of the fuels) [1].

Pemex, the state-owned oil company, holds a monopoly over the country's oil reserves. The oil produced by Pemex generates over 15% of total Mexican import revenues, and the taxes and payments from Pemex account for 40% of the country's governmental revenues [17]. In 2010, 99% of Mexican energy exports (measured in terms of energy content) were comprised of petroleum products, 91% and 8% of crude oil and oil products, respectively. Natural gas exports, by contrast, only represented 1% of energy exports in the same year [18].

Mexican oil production is predicted to have peaked, which is consistent with production over the past few years. Its largest producing oil fields, Cantarell and Ku-Maloob-Zaap (KMZ), are located offshore in the Gulf of Campeche and produced 57% of the country's crude oil in 2009. (While Mexico has some onshore oil production, this production only represents about 20% of its total output.) Although the Cantarell oil field has historically been one of the largest producing fields in the world, its production in recent years has fallen 70% from its peak of over 2 million barrels per day in 2004. The growth of production in the KMZ field has somewhat offset some of that drop in overall national production. Total production in 2009 was approximately 3.0 million barrels per day, down 5.7% from the previous year. The International Energy Outlook 2010 predicts a decreasing trend in crude production in the upcoming years and forecasts that the country might become a net-importer of oil by 2015 [17]. Considering the large dependence of the Mexican economy and federal government on oil revenues, this shift will likely be detrimental to the fiscal health of the country.

In addition to being a major oil producer, Mexico was the 15th largest producer of natural gas in 2009 globally [19]. Proven natural gas reserves in Mexico are estimated to be approximately 13.2 trillion cubic feet. Annual production of natural gas in the country is 1.84 trillion cubic feet.

Mexico's domestic energy consumption is dominated by oil, which comprised about 55% of its energy use in 2007. In 2009, the country was the 12th largest consumer of oil in the world, consuming approximately 2.09 million barrels per day [20]. Natural gas consumption was 2.4 trillion cubic feet in 2009, representing about one-third of the country's energy consumption [17]. Gas use in excess of domestic production is supplied by liquefied natural gas and from U.S. pipelines [17].

Although Mexico is an exporter of crude oil, it is a net importer of refined petroleum products, the majority of which (60%) is gasoline. In fact, oil products were Mexico's largest percentage of energy imports in 2008, comprising 65% of its imports based on the energy content of the imported fuels. Natural gas imports represented about 28%, followed by coal and peat which represented about 6% of the energy content of imported fuels [17].

2.2. Electricity production in Mexico

Mexico is the world's 20th largest consumer of electricity. While 97% of Mexican homes are connected to the grid, more than 3 million people still lack access to electricity, usually in remote regions that are difficult to connect to the grid [21]. Consistent with its role as a large oil producer, Mexico's electricity mix also reflects its vast oil resources, as crude oil is burned to generate 21% of Mexico's electric power. Natural gas and coal are used to generate 44% and 10% of the country's electricity, respectively. The rest of electricity demand is met by renewable sources (18%) and nuclear (5%). In 2009, Mexico generated a total of 239 billion kWh of electricity, as shown in Figure 6, at the power plants shown in Figure 7 [2].

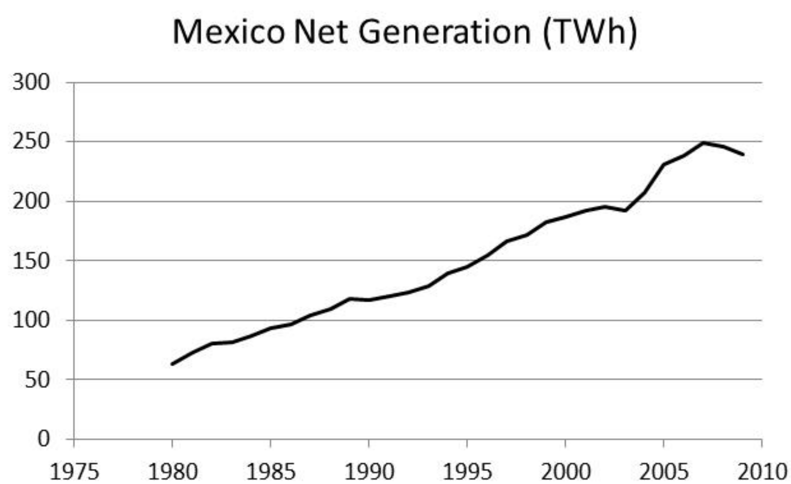


Figure 6. Historical net electricity generation in Mexico [2].

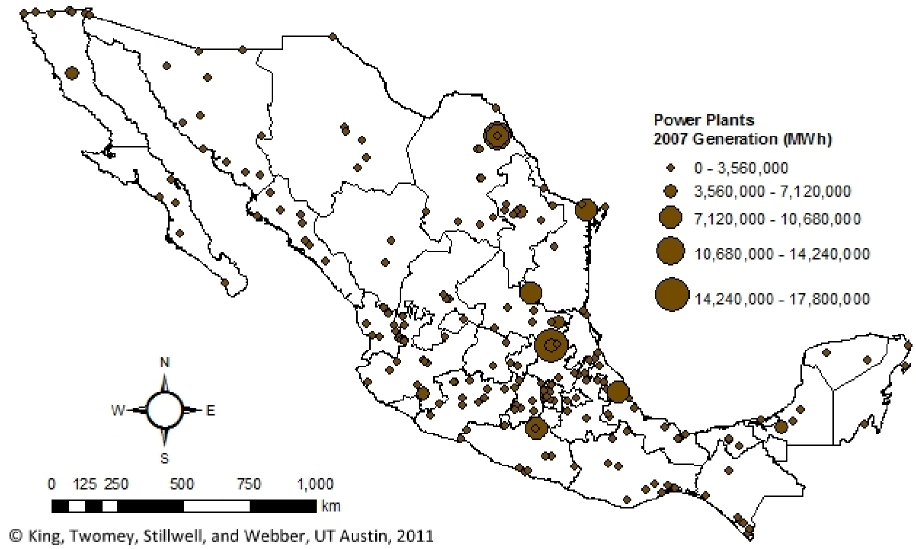


Figure 7. Electricity generation (MWh) in 2007 from Mexican power plants (map created based on data from **[22]**).

Total installed capacity of Mexican power plants in 2008 was 51 GW with 58.2% thermal power plants, 28.8% hydroelectric, and the remainder from "other" renewable, namely wind and geothermal.[2]. Of the 237 electric TWh produced in Mexico in 2008, 65.2% was electricity generated by publicly owned companies. The remaining electricity, 30.4%, was controlled by large foreign investors (LFI). Future projections estimate Mexico's electricity consumption to rise to 900 TWh by 2050. Current electricity demand is growing at 4.4% per year, exceeding population growth of 0.8% per year [21]. The regions projecting the most growth are tourist locations, including the Yucatan, Baja California, and industrial estates of the north.

Two government companies are responsible for electricity generation, transmission, and distribution: the Federal Electricity Board (CFE) and Central Power and Light (LFC). CFE controls approximately 80% of the national electricity system and is responsible for regulating energy and granting licenses in the management of activity development in the sector. CFE's control is under federal jurisdiction and considers technical and economic matters, including market stimulation. LFC controls the remaining 20% of electricity system, focused in the central region [21].

Mexico's electricity system is divided into five regions: northwest, centre, centre-west, south-southeast, and northeast, in order of decreasing consumption. The Electricity system is coordinated by the Secretary for Energy (SENER), the Regulatory Board for Energy (CRE), and the National Board for the Efficient Use of Energy (CONUEE). SENER is the agency dependent on the federal government tasked with coordinating the national energy policy, CRE regulates private participation in the electrical and natural gas sectors, and CONUEE works toward fostering energy savings and efficiency and promoting renewable energy technologies. In 1992, an amendment allowed private parties to invest in electrical power, causing LFIs (>20MW), small producers (<30MW), and self-generators to appear and increase generation. LFIs and small producers can only sell electricity to CFE, who undertakes its distribution [21].

The drop in Mexican government revenues from oil exports (see previous section) is important to consider because internal financing of water infrastructure is expected to become more difficult. As discussed here, Mexico still produces 21% of its electricity from oil-fired power plants – a practice most advanced economies stopped thirty years ago to reduce dependence upon oil. Thus, there is a significant opportunity to replace oil-fired power generation with renewable energy in Mexico to reduce internal oil consumption. Furthermore, new investments in energy infrastructure can possibly be linked to water projects.

2.3. Renewable energy resources in Mexico

Mexico is a country of vast geography and climate patterns. The fourteenth largest country in the world by area, it spans large expanses of dry desert regions in the north, tropical rainforests in the south, and multiple regions of coastal plains and mountain ranges throughout. Many areas, especially in desert regions, receive very little rain, while other regions have ample precipitation and can receive up to 300 cm a year [23]. Mexico's solar radiation resource ranks it among the highest in the world.[21] Currents in the Gulf of Mexico and Pacific Ocean contribute to the vast wind resources at the Isthmus of Tehuantepec. Air temperatures oscillate between 15 and 26 °C, on average. Geothermal resources are abundant due to great tectonic and volcanic activity. The natural landscape also has many lakes and fast-moving rivers that could generate hydropower. Consequently, incorporating renewable energy technologies into the country's diverse regions might be suitable, but must be evaluated based on local conditions [21].

Both incentives and barriers exist within Mexico's economic and political environment for the development of renewable energy. In general, renewable energy interest is derived from fears of lessening oil reserves [21], and many seek to attract foreign investors [24]. However, renewable energy projects often lack funding due to high initial, short-term costs. Also, Mexican culture does not value environmental benefits as much as some other cultures.

Current status of renewable energy

Currently only a small fraction of renewable resources are used to generate electricity, with contributions reaching 14.6% -- 12% from hydroelectricity, 2.5% from geothermal, and 0.1% from wind. CFE is considering the possibility of installing approximately 3.2 GW of power generation from renewable energy sources, including additional wind, hydraulic, and geothermal [21]. Facilities currently exist for wind and hydraulic projects, as well as for biogas collection and utilization from anaerobic digestion of municipal solid waste and manure [21]. Plans for renewable energy on a large scale include SENER's proposed 100-MW wind and 300-MW hybrid (generation using mixed renewable sources or renewable fossil sources) installations [21]. SENER, by means of the IIE, is considering the development of the regional Centre of Wind Technology in Ventoda, Oaxaca, as part of the Action Plan to Remove Obstacles to the Installation of Wind Energy (GEF/PNUD/SENER-IIE) in which the SENER by means of the IIE looks at the development of the regional Centre of Wind Technology in Ventoda, Oaxaca [21]. Many factors and policies promote renewable energies, including the Clean Development Mechanism (CDM) in the Framework of the Kyoto Protocol and the drawing up of a National Program for Rural Electrification by way of renewable energy technologies in the states of Oaxaca, Veracruz, Guerro, and Chiapas [21].

Mexican policies also influence the adoption of renewable energy technologies. In 2003, laws allowing the net metering for renewable energy production were passed. While net metering encourages adoption of distributed renewable technologies, policy mandates have not cemented the future of renewables. As of 2008, electricity and feed-in laws and renewable portfolio standards had not been incorporated into established policies. Policies have, however, been passed that require these laws and standards be developed [25]. Additionally, the National Development Plan for 2007-2012 aims to establish rational and sustainable use of natural resources and the progressive diminution of greenhouse effect emissions, with goals to have a secure supply of energy, diversify primary energy sources, reduce primary impacts of energy sources, and improve the competitiveness of public companies [21].

Hydropower

Mexico has approximately 11.4 GW of installed hydropower capacity that generated 39 and 26 TWh of hydroelectric power in 2008 and 2009, respectively, as shown in Figure 8 [2]. In 2009, a total of 4,000 dams generated 19 TWh/yr. To date, the largest hydraulic plant in Mexico, Chicoasen in Chiapas, has 2.4 GW installed. CRE estimates that hydroelectric generation could reach 80 TWh/yr based on this potential capacity estimate; however hydropower often encounters tough opposition. A large recent installment of 750 MW of hydropower in March 2007 attracted harsh criticism for economic, political, social, and environmental reasons. Another large hydropower installment of 900 MW has the potential to generate 1,529 GWh annually in state of Guerro, but was opposed by ecologist groups [21].

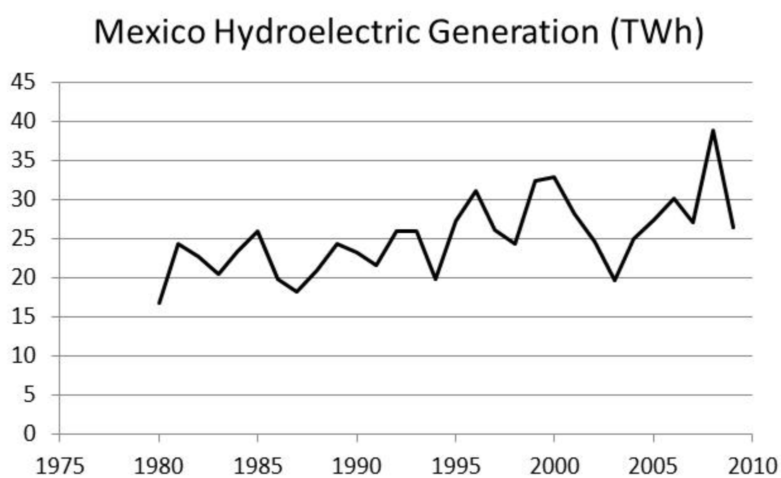


Figure 8. Historical net hydroelectric generation in Mexico. At approximately 11.4 GW (2008) of installed capacity, this generation equates to a capacity factor of 25-40% **[2]**.

Wind

Mexico has vast wind resources, as shown in Figure 9. The Isthmus of Tehuantepec has among the best wind resources in the world and several analyses indicate nationwide wind energy generation potential of more than 40 GW. The year 2007 marked the inauguration of the first large scale wind farm (La Venta II with 83 MW) in Mexico. La Venta III, IV, V, VI, and VII, each 100 MW, are programmed to start operating between 2009 and 2012 and have been started or are currently in the design stage. Such projects, along with wind potential, have motivated plans for wind energy development. CFE plans to construct 1-1.5 GW wind farms in the Oaxaca area and LFIs have promoted the installation of 1.5 GW of wind power, which is expected to start in 2010. SENER has more than 500 MW of wind installations planned in Oaxaca in the LFI modality, which would allow capacity to reach 590 MW by 2014. With these farms the Isthmus of Tehuantepec can expect 585 MW of wind power installed by the end of 2012 [21].

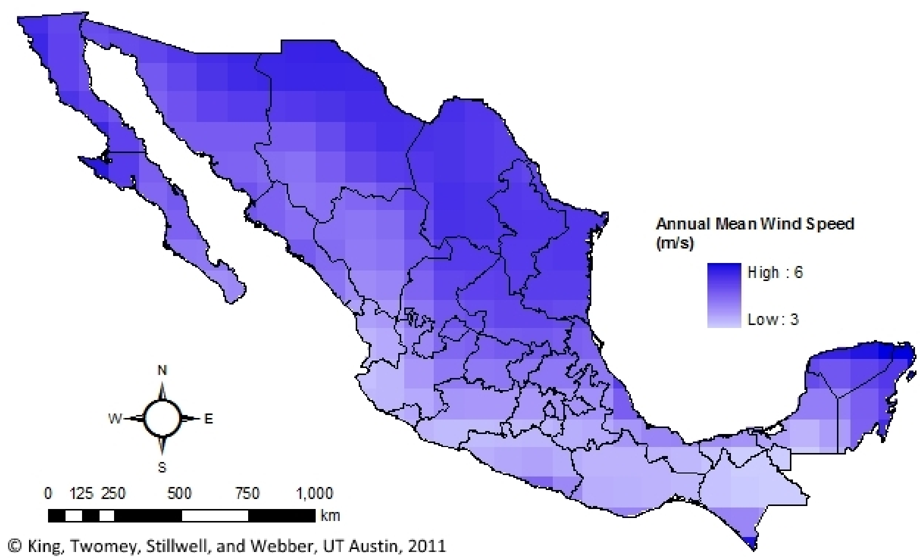


Figure 9. Annual mean wind speed (m/s) at 50 m above Mexican land surface (map created based on data from **[26]**).

Solar

Mexico has enormous solar potential, receiving an average of 5 kilowatt-hours per square meter per day (kWh/m^2/d), as shown in Figure 10. Many of the states close to the Pacific reach 7 kWh/m^2/d, while the rest of the country receives 3 kWh/m^2/d. In 2006, 839,686 m^2 of solar collectors were installed for sanitary hot water, and in 2006, 17,633 kW of photovoltaic modules were installed for rural electrification, communications, and water pumping. By 2013, 25 MW from photovoltaic modules are expected to be online (14 GWh/yr) [21]. Currently, the largest installations are in San Juanico (Baja California) and Agua Prieta Sonora [21].

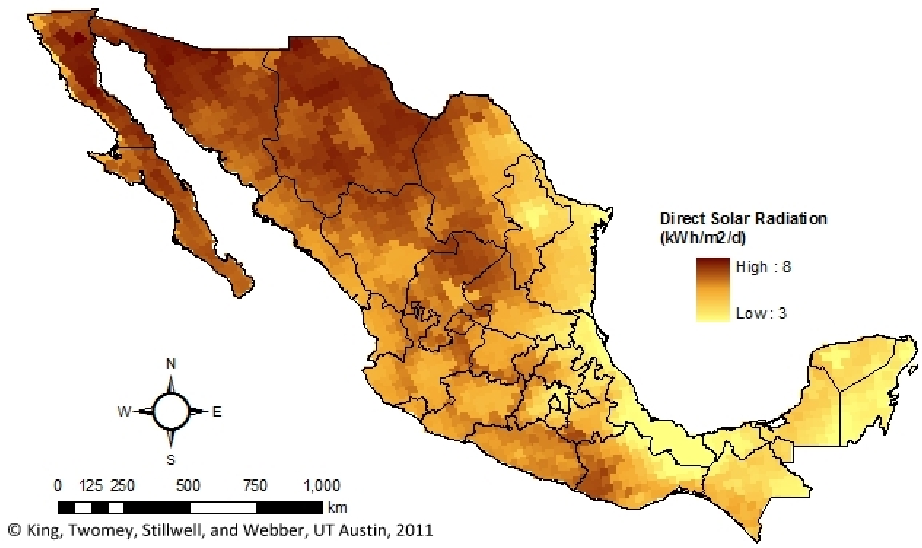


Figure 10. Annual direct solar radiation (kWh/m^2/d) across Mexico (map created based on data from [26]).

Biomass and biogas

Biomass and biogas, primarily wood and sugar cane bagasse, represent 3.2% of Mexico's primary energy consumption. In 2005, the sugar industry produced 5 million tons of sugar and 56 million liters of ethanol [21]. Ethanol production started in 1999 (in Veracruz), although no legal framework for ethanol for biofuels was made until 2007, so ethanol was originally used in the pharmaceutical sector. In 2008 under the Law for the Promotion and Development of Bio-fuels, the sugar industry was able to produce electricity and ethanol for both the electric and transportation sectors [21].

Decentralized production of bioenergy holds a lot of potential, particularly in the case of raw materials such as Jatropha, castor oil plants, and biogas. These sources can be converted into energy through simple technologies that are be easily installed on site and, as in the case of Jatropha, can be grown on marginal lands or through intercropping [7]. In 2005, CRE authorized a 19-MW biogas project to generate 120 GWh/year, a 70-MW sugarcane bagasse facility to generate 105 GWh/yr, and a 224-MW hybrid, petroleum and sugarcane bagasse project to generate 391 GWh/yr. Municipal, farming, and forest solid waste products available for electricity production are estimated to total 73 million tons, which could generate 4.5 GWh/yr (803 MW). The total energy available from biomass is estimated between 2,635 and 3,771 PJ/yr [21].

Electricity from biogas has become a popular mode of renewable energy generation. Bio-energy of Nuevo Leon constructed a facility (online September 2003) to generate 7 MW of electricity from biogas produced via anaerobic digestion of municipal solid waste. Monterrey Water and Drainage Services became a self-supported facility after generating electrical energy from biogas (10.8 MW) [21]. These examples illustrate the potential for distributed energy biomass and biogas to couple with water resource management in Mexico.

Geothermal

Mexico has installed 960 MW of geothermal power, generating 7,404 MWh/yr of electricity [21]. Geothermal electricity production decreased slightly to 6,400 MWh/yr generated from 964 MW in 2009 [2]. Yet Mexico still ranked 3rd in the world for geothermal energy production in 2009 [2, 25]. Resource reserves are estimated to be 1.3 GW, with 4.5 GW listed as "probable". Current exploitation of high-temperature resources is 853 MW and medium-temperature resources is 107 MW. Geothermal electricity generation is regulated by the "Law of National Waters", Article 81, which states: "The exploitation and use of or benefitting from subsoil waters in the form of steam or with a temperature greater than 80 °C, when it may affect an aquifer, will require previous permission for geothermic generation or other uses besides an assessment of environmental impact…'' however, no regulations are in place under this article. Despite large resource potential, high capital cost for drilling equipment and infrastructure suitable for hot rock hinders exploitation [21].

Tidal

No tidal energy projects are currently in development in Mexico, but large potential exists in the Sea of Cortes off the peninsula of Baja California [21].

2.4. Renewable energy policy in Mexico

Energy policy, including renewable energy policy, in Mexico is regulated by the Secretary for Energy (SENER). Under SENER, many laws have been enacted pertaining to renewable energy, including the organic law for Federal Public Management, laws for the Regulatory Energy Committee, internal regulations for the Energy Secretary, internal rulings for CONUEE, and official Mexican regulations regarding electricity matters, energy efficiency, thermal efficiency, natural gas, and nuclear safety. On June 27, 2007, the official federal contract for the interconnection to solar energy on a small scale was also published and is applicable to solar generators less than 30 kW. Other chief government institutions taking part in renewable energy development include the Secretary of Energy, CRE, and CONUEE, along with the Institute for Electrical Research to develop studies for non-conventional energy, Federal Electricity Board that is responsible for public electricity supply, the Light and Power for the Centre with the same functions as the CFE, the Secretary for the Environment and Natural Resources to draw up environmental and natural resource conservation policies, and the Secretary for Social Development (SEDESOL) to promote projects for the exploitation of renewable energy [21].

Additional policies affect renewable energy in Mexico. The Law for the Exploitation of Renewable Sources (LAWRE) set a 2012 goal of renewable energy, excluding large hydroelectric dams, representing 8% of the total electricity generated in Mexico. Under LAWRE, 30 million dollars each year will go towards fostering less developed technologies, advancing technological development and research, and developing the regional social and economic environment. LAWRE is not concerned with biofuels, but the Law for the Promotion and Development of Bioenergies from February 2008 promotes the use of ethanol and other bio-carburetants [21].

Official Mexican Norms were established as tools for authorities to set up requirements, specifications, conditions, and procedures, and to regulate the exploitation of natural resources for economic purposes. These tools also play an essential role by creating a climate of legal certainty to promote technological change to achieve more efficient environmental protection. PROY-NOM-15-SEMARAT-2006 is one of the most significant norms regarding renewable energy exploitation. Though it is still in the planning stages, PROY-NOM-15-SEMARAT-2006 established the technical specifications for environmental protection during the building, running, and closing of wind electrical installations in cattle and crop farming and untilled land areas [21].

3. Water resources, drought, and climate change in Mexico

The impacts from drought and climate change in Mexico, particularly northern Mexico, closely mimic those of the southwestern United States. Research studies show that El Niño Southern Oscillation (ENSO) events are highly influential in determining precipitation in northwestern Mexico and the Sonoran desert region (see Figure 11). There is also considerable seasonal and annual variability in precipitation. In southern and central Mexico higher precipitation is normal in the tropical and higher altitude regions, but collecting and transporting this water to areas of high population, primarily Mexico City, presents some engineering challenges. In this section we focus upon describing precipitation patterns in the northern portion of Mexico.

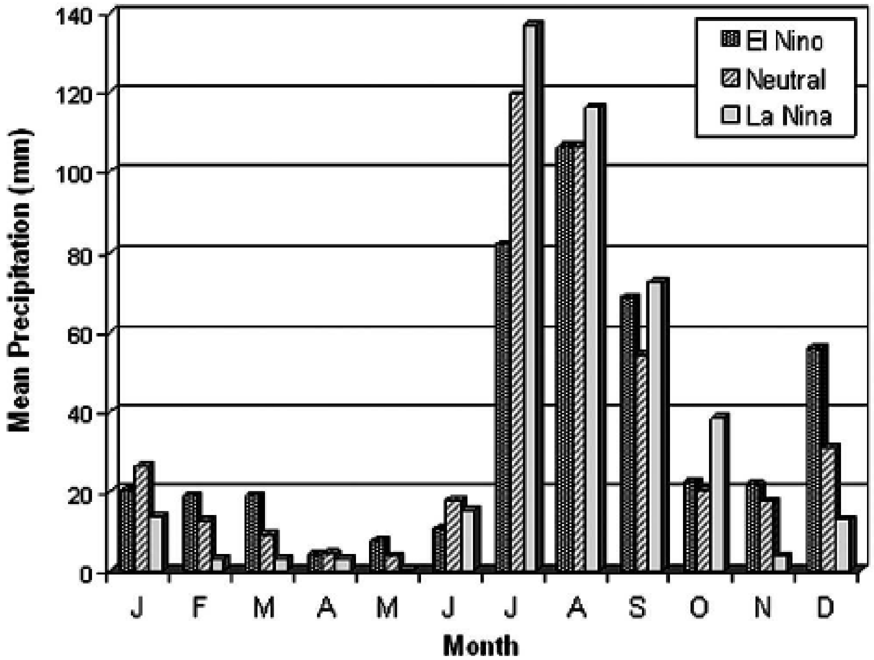


Figure 11. Precipitation in Sonora region is highly affected by ENSO events [27].

In comparing the current drought at the beginning of the 21st Century [1998-2004], Seager (2007) shows that a La Niña pattern of cooler Pacific Ocean temperature exists that is similar to the five prior persistent droughts. However the five previous droughts also occur with a cold Indian Ocean, usually characteristic of La Niña, which is not consistent with the most recent drought. Thus, research suggests that the earlier period of this most recent drought is the latest in a series of multiyear droughts forced by persistent changes in tropical Pacific Ocean temperatures. Climate modeling has begun to reveal that one of the main causes of North American droughts is the persistent reduced precipitation across the American West occurring during times when the tropical Pacific Ocean is anomalously cold, a "La Niña–like state." [28]

Drought periods in northern Mexico are expected, but unusual, events. The return period, or amount of time expected between 10 year drought periods, is 30-80 years [27]. Forty to eighty percent of the annual precipitation in the Sonoran region falls during the summer monsoon season (see Figure 11). Today, most of Mexico and the Southern United States are experiencing a current extreme drought period (see Figure 12).

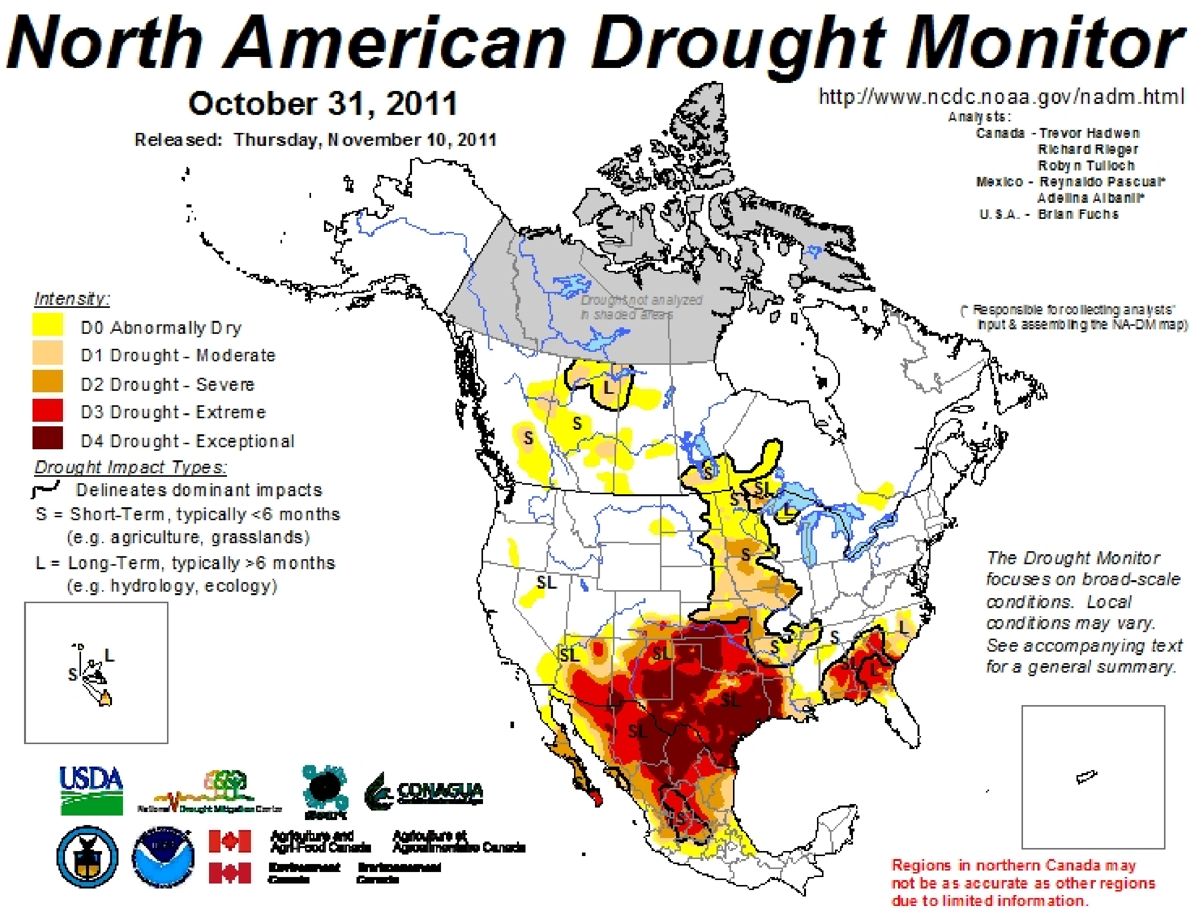


Figure 12. North American Drought Monitor map for July 31, 2011 [29].

Hallack-Alegria and Watkins summarizes nicely the precipitation patterns of the Sonora region [27]:

> "Winter precipitation is usually associated with relatively long-lived frontal systems that approach Sonora from the Pacific Ocean, and these events are typically more effective in terms of recharging soil moisture and groundwater supplies than warm season precipitation events. This is mainly due to two factors: 1) summer precipitation is often very intense, falling at high rates in short periods of time over discontinuous areas, and large amounts of water sometimes run off the surface rather than infiltrating deep into the soil, and 2) high summer temperatures cause high evaporation rates, leaving little or no surplus of surface moisture for storage [30]. Also, since the atmospheric phenomena that originate warm and cold season precipitation are very different, seasonal rainfall totals tend to be uncorrelated with each other, and thus separate cold season drought frequency analysis is warranted. Details of drought frequency analysis for the cold season may be found in Hallack-Alegria (2005) [31], who also investigated the potential for cold season precipitation forecasting. Preliminary analysis showed significant correlation between

warm season ENSO phenomena and winter precipitation, with La Niña events consistently leading drier-than-average winters."

Thus, ENSO and La Niña are highly influential in determining drought events, which means that there is potential to use forecasting and measurement to anticipate and prepare for drought. Preparations can include altering the timing of planting of crops and/or water storage. The use of renewable energy installations, particularly solar photovoltaics, to power remote monitoring stations could play a significant role in both measuring and adapting to drought and climate change.

Despite the good evidence of the link between La Niña and southwestern North American droughts, there is some evidence that human factors, both due to local land cover changes and global climate change, might be exacerbating the current drought. A significant drought period started in 1994, lasted through 2005, and is continuing during the present day. As noted by Stahle (2009) [32],

> "This late twentieth-and early 21st-century Mexican drought … has equaled some aspects of the 1950s drought, which is the most severe drought evident in the instrumental climate record for Mexico (1900–2008). Large-scale changes in ocean-atmospheric circulation have contributed to the lower than normal precipitation that has led to the current drought [28], but global warming and the sharp regional warming across Mexico, which appears to have been aggravated by land cover changes [33], may have added an anthropogenic component to the early 21st-century drought."

Engelhart and Douglas (2005) [33] investigated the temperature change trends in Mexico over much of the last 20th Century. Aside from atmospheric climate-related anthropogenic changes, there are possibly anthropogenic land cover changes that have increased maximum daily temperatures and decreasing the evaporative cooling effect for local areas while increasing the absorption and release of stored heat from land surfaces that overwhelms any increased reflectivity from removing vegetation [33]. Englehart and Douglas (2005) also report that the diurnal surface temperature range (DTR = maximum daily temperature (T_{max}) minus minimum daily temperature (T_{min})) of Mexico seems to show the opposite trend for the rest of the hemisphere. While the hemisphere overall shows decreasing DTR from 1970-2001, in much of Mexico the trend is for increasing DTR over this time period. For the time period from 1940-1970, DTR in Mexico is estimated to have been decreasing. In other words, in the recent decades in Mexico, T_{max} is increasing faster than T_{min}. Some of this trend is believed to be reducing the vegetative cover either from grazing or agriculture, and thus reducing the ability of the soil to hold moisture due to increased runoff, among other factors. With less moisture in the soil, there is less evaporative cooling during the day, and hence higher T_{max}.

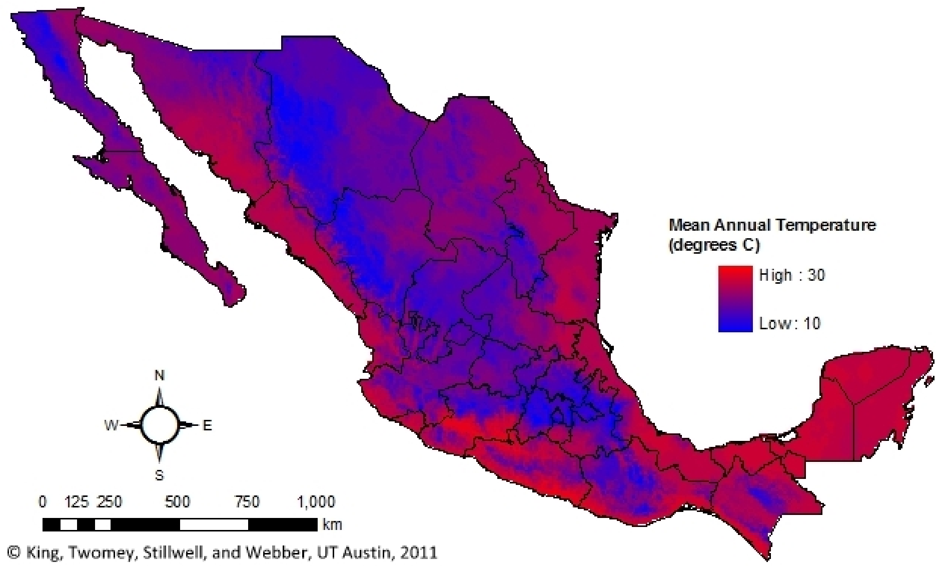
Stahle also adds that the current drought has likely only been exceeded by droughts during the 1950s and 1560s [32]. Thus, while there are few data points to suggest increasing frequency of extreme drought events, it seems possible that increasing global temperatures can be enhancing the effects of normal ENSO events. That is to say, the vast majority (18 of 19) climate simulations show that "Dust Bowl-like" droughts are likely to become more of the normal climate of southwestern North America that includes northern Mexico [34]. The "Dust Bowl" of

1932-1939 was characterized by reductions in precipitation of 0.09 mm/day and the 1950s drought (1948-1957) was characterized by reductions of 0.13 mm/day. The median result from the climate models analyzed by Seager et al. (2007) indicates a reduction in average precipitation (as compared to the time period from 1950-2000) of 0.1 mm/yr by the middle of the 21st Century [34].

The North American Drought Monitor indicates that abnormal drought affected large portions of Mexico during the summers of 2006 and 2007 and that by June 30, 2008, most of Mexico was under drought, including extreme drought over portions of west central Mexico [32]. Heavy rain alleviated drought across portions of northern Mexico during late summer 2008, but drought has persisted across central and northwestern Mexico up to the writing of this report (December 2011). The drought persisting over the years of 2009 and 2010 marked one of the most severe in terms of water scarcity; during some months as many as 5 million people lacked sufficient access to water.[12] Figure 12 shows that as of this writing the drought situation in Mexico is severe. MacDonald et al. (2008) note that a megadrought of the 12th Century was marked by increased radiative forcing and climate warming [35]. They go so far as to suggest that because of anticipated ongoing warming from global climate change, the latest North American drought could be signaling a transition to a state of persistent aridity and more prolonged droughts [35].

Figure 13(a) maps the current mean annual temperatures in Mexico, and Figure 13(b) is a projection of the mean annual temperatures in 2050 under a nominal climate and energy scenario of the Intergovernmental Panel on Climate Change, balancing development of fossil and non-fossil energy resources. It is clear that higher mean temperatures are expected. Together with less precipitation expected for northern Mexico, the northern parts of Mexico could find increased struggles in producing agricultural products and supplying water to municipalities in an already arid region of the world. Figure 14 shows the anticipated 2050 precipitation that corresponds to the temperature profile in Figure 13(b). By comparing Figure 14 to the current mean annual precipitation in Figure 3, one can see the subtle nature of anticipated lower precipitation. Thus, the anticipated decline in annual rainfall for Mexico is one aspect to consider for future adaptation, but the drought scenarios caused by several concurrent years of below normal precipitation need other adaptation measures that can make the most use of rain events when they do occur.

(a)



(b)

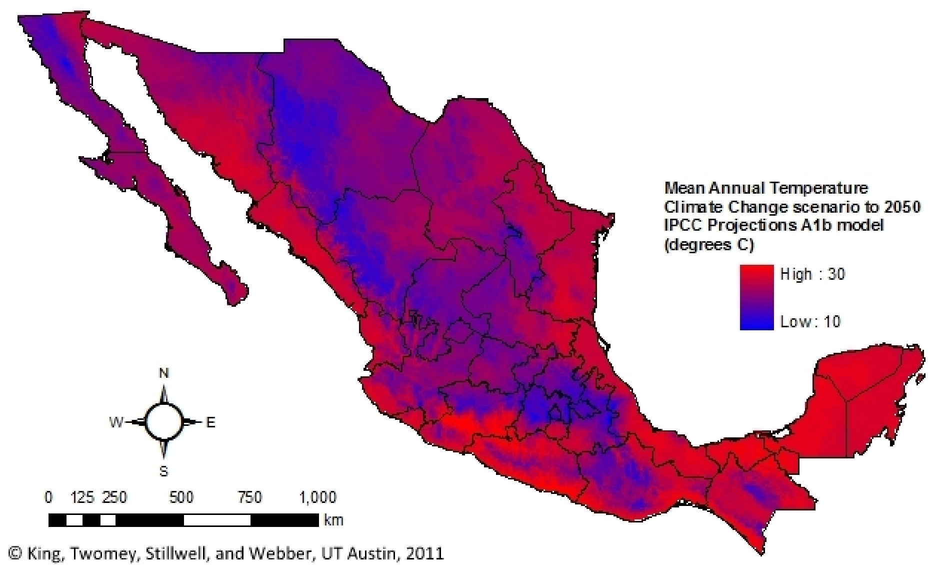


Figure 13. Current mean annual temperature (°C) across Mexico (a) and projected mean annual temperature (°C) in 2050 (b) under Intergovernmental Panel on Climate Change (IPCC) model A1b balancing development of fossil and non-fossil energy resources (map created based on data from **[8]**).

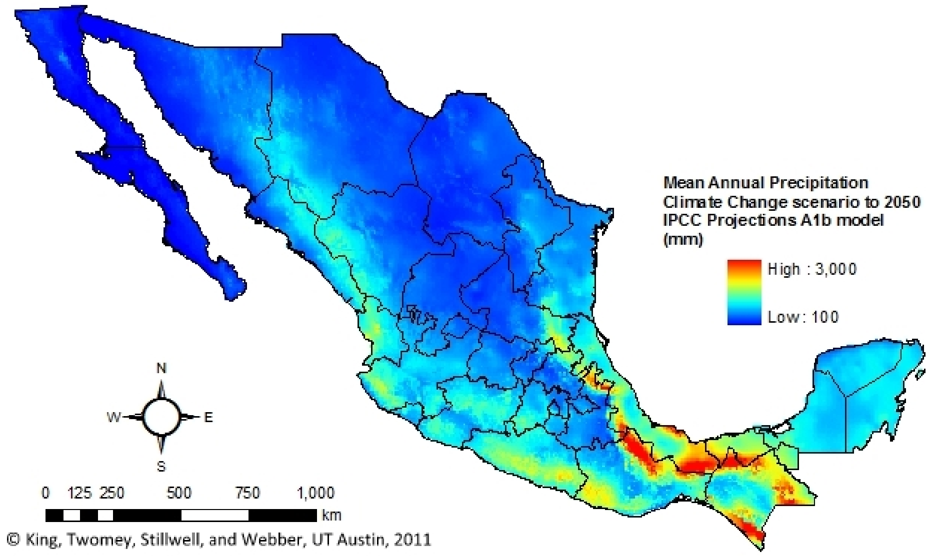


Figure 14. Projected mean annual precipitation (mm) in 2050 across Mexico under Intergovernmental Panel on Climate Change (IPCC) model A1b balancing development of fossil and non-fossil energy resources (map created based on data from **[8]**). Refer to Figure 3 for comparison to current mean annual precipitation.

Chapter 2. Energy-water nexus tools

1. Policies and technologies relevant to the energy-water nexus

This section provides a *qualitative* description of policy objectives and the technologies and policy options that help achieve the objectives that have relevance to the energy-water nexus. This chapter is not specific to Mexico, but it is generally applicable for developing countries that have water services and infrastructure that are either of low quality or not fully distributed to all citizens. Chapter 3 discusses some specific opportunities for Mexico.

Within the context and constraints of each region of the world, the best technologies and policies for each region are likely to be different. And, just as energy and water are intimately coupled, so too are policies and technologies that affect the energy-water nexus. Thus, while some technologies leverage policy changes, some policies encourage or need technology to be effective.

Table 1 summarizes the textual descriptions of technology and policy that follow, with a focus on distributed technologies for water and/or energy. For each of these policy and technology options, economic factors and price feedbacks are not directly considered in this section. We discuss issues of financing and costs of implementing water and energy technologies later in this report.

2. Description of policy objectives

Nations have different policy objectives related to energy, water and carbon. Some of the most relevant and universal objectives for the energy-water nexus are listed here and used as an organizing framework for this discussion (and organized by appropriateness for different technologies in Table 1).

Water security relates to consistent and reliable availability of potable freshwater or the services it provides. Efforts that increase freshwater supply, reduce freshwater consumption for the same level of service (efficiency), or conserve freshwater consumption in aggregate (conservation) enhance water security.

Energy security[3] relates to consistent and reliable availability of energy resources or the services they provide. Efforts that increase energy supply, reduce energy consumption for the same level of service (efficiency), or conserve energy consumption in aggregate (conservation) enhance energy security.

Increased *water quality* relates to efforts to mitigate impacts from human activity that alter the ambient natural aquatic environment due to, but not limited to release of total

[3] As used here, *energy security* does not address concerns of wealth transfer or supply chain reliability from trade of energy resources between countries.

dissolved solids, unnaturally warm or cold water, dissolved gases, and dissolved nutrients.

Carbon management relates to efforts that reduce or avoid anthropogenic greenhouse gas (GHG) emissions in aggregate or sequester carbon from the atmosphere. To assess impacts of carbon management from increased energy consumption, the following sections assume energy comes from a typical worldwide fossil energy mix. Thus, the default assumption is that higher energy consumption equates to higher GHG emissions.

Renewable energy relates to efforts that generate more energy from solar (sunlight, wind, waves, biomass), gravitational (tides and falling water), and geothermal resources.

3. Description of policy choices

A variety of policy options are available for countries to pursue their policy objectives discussed above. While the discussion in this section and the information organized in Table 1 focuses on different technological solutions and the policies that enable their widespread adoption, it is important to note that behavioral changes are also an important piece of the policy discussion. In particular, even technologies that are cost-effective to implement (e.g. they pay for themselves within a reasonable timeframe) and for which there is policy support often do not get implemented because of behavioral, cultural, or financial hurdles [36, 37]. Some of the barriers that remain—even for technological solutions that are cost-effective—include the following [37]:

- Potentially high up-front costs
- Alternative uses for investment capital that appear more attractive
- Volatility in energy prices (which creates uncertainty in payback times)
- Lack of information to consumers about relative performance and costs of alternatives
- Substantial investments in time and effort might be necessary to find/study relevant information
- Purchasers focus on up-front costs, NOT lifecycle costs
- Risk aversion—new products and methods are unfamiliar
- Lack of local expertise and training for technology/system maintenance

In addition, there are important structural gaps, whereby the people or institutions that make the investment decisions for energy- or water-efficient technologies are different than the people or institutions that benefit. Two classic examples of this conundrum are: 1) landlords pay for the capital for buildings (including appliances, windows, insulation, heating/cooling systems, etc.), while tenants pay the energy and water bills, and 2) homebuilders select the capital stock, but homeowners pay the energy and water bills. Examples of successful policies and programs to bridge inconsistencies between building/homeowners and tenants include [37]:

- Efficiency standards for vehicles and appliances
- Product labeling and promotion

- Building energy codes

It is important to note that there are also cultural pressures that impact decision-making. For example, for a variety of historical and cultural reasons, Australians are typically much more water-conscious than Americans, and Europeans are typically much more energy-conscious than Americans. These cultural attitudes manifest themselves in individual decisions to conserve energy and water, even when policies or economic arguments do not require or justify those actions. Cultural shifts may arise in Mexico in the near future as future government revenues shrink due to declining oil production and export. Some typical policy choices for the energy-water nexus are considered here (and organized by appropriateness for different technologies in Table 1), based on traditional policies that are available and including the effective policies listed above.

Public relations (PR) and community engagement encompass targeted educational and outreach activities (e.g. public service announcements) that inform consumers or stakeholders who can take direct action upon learning about a topic of interest. PR campaigns include informing the public about the science, economics, or government involvement regarding water and energy issues and resource management.

Data gathering involves data collected on multiple scales from aquifers to the wider scales of cities and countries that can be used to create statistics for policy decisions and track whether policy decisions produce intended outcomes (e.g. sustainable aquifer pumping and recharge). This strategy includes surveys of local communities and can be a part of the community engagement process such that policies can be tailored to local economic and social needs.

Mandates and regulations encompass government laws and rules that consumers and businesses must follow to avoid civil and/or criminal penalties. Water or energy quotas and allocations are included in this category, as are building codes, efficiency standards, and so forth.

Right-pricing and full-cost recovery describe policies ensuring that energy and water tariffs (or charges) are sufficient to cover the full supply costs of energy and water (including the operation and maintenance costs and the capital costs for renewing and extending the energy or water system), and ultimately opportunity costs (scarcity value) and externality costs (economic and environmental) [38]. Included in this definition are concepts such as ecological zoning and carbon pricing as means to incorporate externalities. Unfortunately, in most situations, what is considered a cost-recovering scarcity price lies beyond the average income levels of rural populations. Welfare-oriented development doctrines, therefore, militate against the notion of market prices for electricity on the grounds that they would inhibit rural socioeconomic development, the benefits of which cannot be measured in financial terms alone [39].

Government subsidies encompass targeted monetary incentives given by the government to specific projects, categories of projects, or industrial sectors.

Financing as a policy includes options that enable private businesses and consumers to spread the capital costs of technology over time rather than paying 100% up-front. Examples include traditional loans as well as concepts such as Property-Assessed Clean Energy financing where capital costs of renewable energy and energy efficiency projects are blended into the property owner's annual taxes or other government fees [40].

4. Specific policy and technology relationships

Table 1 illustrates a sample list of technologies that are relevant to the energy-water nexus for rural and developing locations. These various technologies can interact with water and energy social and policy objectives in different ways. For each listed technology (left column), a relationship to policy objectives is given as follows: an up arrow (↑) indicates that the technology helps to achieve the policy objective, a down arrow (↓) indicates that the technology hinders achievement of the policy objective, a level arrow (↔) indicates that the technology has choices and tradeoffs that make its effect upon the policy objective site-specific or unclear, and dashes (--) indicate that the technology has no appreciable impact on the policy objective. In situations where a technology can be used for widely varying purposes, multiple arrows indicate the outcome can be different depending upon the application. The ● symbol indicates policy choices that can be effective in affecting increased or decreased use of a technology, and the ○ symbol indicates policy choices that are only moderately effective. The effectiveness of a particular policy in promoting a technological solution is independent of whether that solution produces good or bad outcomes for the policy objectives. In other words, it is often possible to craft a policy that is effective at creating a negative outcome for any one policy objective.

The technologies listed in Table 1 are selected among many to display primarily those with promise for developing economic areas that have little access to capital. For many of the technologies, such as photovoltaic (PV) systems, wind turbines, and geothermal heat pumps, there can be significant needs to maintain highly technical equipment that requires specialized training and materials.

The technologies in Table 1 are listed in an approximate order of increasing scale (top to bottom) of the decision-making body. For example, the installation of low-flow fixtures in a home is a decision and act that a personal consumer can make, but approving and allocating funds for even a relatively small biomass combined heat and power facility might require coordination and investment by multiple community members and/or government municipalities.

Several technologies from Table 1, show a "win-win" scenario in terms of reaching both energy and water security: low-flow fixtures, energy-efficient appliances, rainwater collection for non-potable uses, solar hot water heating, geothermal heat pumps, solar PV and wind power, combined heat and power, hydropower, and converting municipal waste to energy. Other technologies have various tradeoffs: groundwater pumping and greywater reuse for potable purposes. Other technologies have mixed benefits for energy and water security. We list the impacts on the additional policy objectives of carbon management, renewable energy, and water quality as those that have more indirect relationships with obtaining water and energy security from a quantitative standpoint. The technologic impacts on these other three objectives are quite varied.

Notably, two policies—namely right-pricing and mandates—are deemed "effective" or "moderately-effective" for a wide range of technologies. These two policy approaches represent different forms of policy intervention: 1) mandates tend to be more direct and command-and-control oriented (e.g. requiring homebuilders to install solar hot water heaters, implementing building codes), whereas 2) right-pricing approaches are indirect and market-oriented (e.g. allowing prices for energy to increase with the intent that they would cause homebuilders to install solar hot water heaters, or charging households the full price to pay off loans for renewable and energy systems over multiple years). That these policy categories can both be widely-effective despite their very different approaches is important to keep in mind for policymakers. Furthermore, they are not mutually exclusive of hybrid approaches that work to minimize any existing subsidies. That is, many approaches can be used simultaneously. Lower capital cost items are more controlled by individual consumers and the companies selling the products. The government can generally use efficiency mandates and product labeling standards to facilitate the adoption of lower-cost consumer goods and appliances. Higher capital cost items and systems can use financing or community engagement for collective action.

Table 1. A list of technology and policy tools that can be used in combination to achieve certain policy objectives for securing clean water access in development or remote rural economies.

Distributed energy-water technologies and systems applicable for region

Technologies	Policy Objectives					Policy Choices that can influence use of Technologies				
	Water Security	Energy Security	Water Quality	Carbon Mgmt.	Renewable Energy	Public Relations and Community Engagement	Mandate/ Regulation	Right Pricing	Subsidy	Financing (micro and macro)
No/Low-flow plumbing fixtures	↑	↑	--	↑	--	○	●	○	●	
Energy-efficient appliances	↑	↑	--	↑	--	○	●	○	●	
Distributed rainwater collection (non-potable uses)	↑	↑	↑	↑	--	○	●	○	●	
Distributed rainwater collection (potable uses)	↑	↓	↑	↓	--	○	●	●	●	○
Solar hot water heating	↑	↑	↑	↑	↑	○	●	●	●	○
Solar distillation of saline water sources	↑	↑	↔	↑	↑	○			●	○
Geothermal heat pumps	↑	↑	↔ to ↑	↑	↑	○	●	●	●	○
Groundwater pumping (coupled to renewable electric sources)	↔	↓	--	↓	--		●	●	●	○
Residential/building scale solar photovoltaic	↑	↑	--	↑	↑		●	●	●	●
Residential/building scale and community owned wind power	↑	↑	--	↑	↑		●	●	●	●
Desalination by distributed renewable electricity or heat	↑	↓	↔	↑	↑			●	●	○
Municipal waste and wastewater to energy	↑	↑	--	↑	↑		●	●		
Combined Heat and Power (connected to local biomass combustion)	↑	↑	--	↑	↔		●	○	●	○
Hydropower	↑	↑	↓	↑	↑		●	○		●
Irrigated agriculture	↓	↓	↓	↔	--		●	●	●	
Greywater and reclaimed water use	↑	↔	--	--	--		●	●	○^	○^

○^ Greywater use applicable for residential and commercial buildings is most applicable for help from subsidies and financing.

(blank) not likely effective ○ somewhat effective ● effective

No and low-flow fixtures:

Policy Objectives: Toilets that require less water per flush subsequently reduce water consumption, the volume of wastewater requiring treatment, and the embodied energy consumed for water and wastewater distribution, especially when potable water is used. Low-flow shower-heads promote water conservation for similar length showers, and because showers involve the use of hot water, they reduce the size and/or need for infrastructure as well as primary and secondary energy resources required to heat the water. Subsequently, both water and energy security are achieved as less energy is required for both pre-treatment of clean water and post-treatment of the wastewater after showering. The lower energy consumption in the supply chain reduces the need for the water associated with production and conversion of the energy resources, including power plant cooling, as well as GHG emissions associated with fossil energy production. In using distributed energy technologies to pump and treat water, less capacity is required.

Policy Choices: Because low-flow fixtures are low-cost consumer items, effective policies can give away the items or inform consumers of the low cost and environmental benefits to induce change. It is also effective to label products for water efficiency as a method of educating the consumer to distinguish between products. Governments may also mandate use of low-flow fixtures in new construction. Full-cost recovery pricing of water, wastewater, and energy provides proper feedback to the consumer regarding use of fresh and hot water for non-potable home needs. Although, for lower-income regions cost-recovery is less likely to be a factor. Replacing older toilet and shower fixtures has proven to be an effective policy in 1989, when the government required that toilets using an average of 16 liters per flush be replaced with models requiring 6 liters per flush. This policy option was revisited during the drought of 2009 when the Mexican government made a goal to replace 4.7 million showers and 1.7 million toilets with more water-efficient models. Achieving this goal will bring estimated water savings of approximately 7000L/s as compared to baseline 2009 water consumption.[12]

Energy-efficient appliances:

Policy Objectives: Appliances, such as clothes washers and dryers, dishwashers, and televisions that require less energy require less embodied water in the energy. The lower energy consumption by the appliance reduces the need for the water associated with the life cycle production and conversion of the energy resources, including power plant cooling, as well as GHG emissions associated with fossil energy production. Energy-efficient appliances also enable more services to be provided by distributed energy technologies that are expensive and/or capital intensive.

Policy Choices: Appliances are items for which consumers normally budget or purchase outright. Thus, product labeling and PR campaigns can provide information for proper purchase selections. Additionally, governments often set standards for energy efficiency of appliances such that manufacturers have clear targets. For products that go beyond efficiency standards, the government can provide rebates to consumers to adopt new and efficient technologies. Financing, including microloans, may also be appropriate when the appliance either enhances the purchaser's business cash flow or enables more time to be spent generating income. The correct pricing of energy is very critical in allowing the consumer to make the proper choice in purchasing appliances that consume considerable energy over their lifetime.

Distributed rainwater collection (potable and non-potable uses):

Policy Objectives: By collecting runoff rainwater from residential and commercial building roofs, water is captured in a relatively pure form but water treatment is required to make it potable. For non-potable uses, such as irrigation, rainwater collection diverted from creeks and storm drains aids energy security by avoiding energy consumption for distributing water with a centralized system. In treating distributed water to potable standards, smaller treatment systems, such as ultraviolet technologies that kill pathogens, require more energy per liter than municipal scale water treatment. Additionally, the energy consumption for running the individual water pumps at each building is more than that from a centralized municipal system [41], thus decreasing energy security. Water consumption is indirectly decreased by the use of decentralized systems because users tend to conserve more when they know the location of their water supply, and a rainwater collection tank makes this source readily apparent. The carbon emissions associated with the extra energy consumed to treat distributed rainwater hinders carbon management. In some regions of the world, particularly dense cities with a high percentage of impervious ground cover, stormwater runoff can overwhelm wastewater treatment facilities causing overflows of sewage into local waterways that hinders water quality. By collecting and absorbing rainwater (e.g. on green roofs) on many buildings and homes, the surge of the stormwater is mitigated and delayed to keep the existing wastewater treatment facilities with combined sewers below maximum capacity.

Policy Choices: Rainwater collection can be relatively cheap when not using the water for potable uses, and the extra capital investment to treat the water to drinking quality can be helped by subsidies and financing mechanisms (e.g. those that include the costs into mortgage payments). In some cases, zoning policies and water rights laws can actually prevent home and building owners from legally collecting water that falls on their property. Thus, water rights laws and regulations can heavily influence the integration of rainwater collection. Public relations campaigns can inform home and building owners of the benefits and subsidies (i.e. free rain barrels from the government) of using rainwater collection for irrigation and stormwater runoff prevention.

Solar hot water heating:

Policy Objectives: The direct use of renewable solar energy to heat water enhances energy security by minimizing the need for primary energy (e.g. fossil fuels, biomass) and secondary energy (electricity) while also enhancing water security and quality by reducing the water requirements for mining of fuels and cooling of thermoelectric power plants. The elimination of the need for grid-based electricity eliminates GHG emissions associated with fossil-fueled power plants.

Policy Choices: Governments can mandate the use of solar hot water systems on residential (e.g. Israel, Hawaii) or commercial construction. Subsidies also help promote retrofitting of solar hot water systems on existing buildings and homes to offset the up-front capital cost. A public relations campaign can inform citizens that this is often the most cost-effective technology for incorporating renewable energy into their home, and over time saves money by eliminating the need for heating fuels. Proper labeling of all hot water heaters enables consumers to effectively compare solar hot water systems to those powered by electricity, natural gas, or other fuels. Because solar hot water systems are applicable for retrofitting existing homes and businesses, some financing assistance can help overcome the up-front capital expense of integrating the system into the existing home plumbing.

Solar distillation:

Policy Objectives: Solar distillation systems are designs based somewhat on a greenhouse design to evaporate brackish or saline water and condense it on the bottom of a tilted surface. The now evaporated fresh water is collected at the edges of the tilted surface. Solar distillation systems enhance energy security in areas with sufficient sunlight and heat. Also, they enhance water security by enabling the use of non-fresh water sources as input to output water of drinking or irrigation quality. Because there are few moving parts associated with solar distillation designs, they are often seen as easier to maintain in remote communities that lack skilled technicians to fix more technological-based systems (e.g. reverse osmosis membranes and filters).

Policy Choices: Solar distillation systems are applicable for residential and commercial scale water supplies depending upon the size of the structure. Thus, subsidies and financing can help incent the up-front investment in new construction. Public relations campaigns and community engagement can help educate and inform consumers, businesses, and communities of the costs, benefits, and operational aspects of solar distillation systems.

Geothermal heat pump:

Policy Objectives: Geothermal heat pumps use the relatively constant temperature of the shallow earth to regulate room temperature in both cold and hot climates. This technology lessens the need for primary energy (e.g. natural gas, heating oil, biomass, and fuels burned for thermoelectric power) for heating and cooling to enhance energy security. This use of the carbon-free energy from the earth helps carbon management, and geothermal heat is normally considered a renewable energy resource. Water security increases as well because of reduced water requirements for mining of fuels, cooling of thermoelectric power plants, and hydropower operation. The working heat transfer fluid of closed-loop designs stays within the system, thus no external water is required, and water quality is not affected for properly functioning systems. However, open-loop systems exchange water with underground aquifers and present opportunities for thermal water degradation if not designed properly. Thus, proper design and use of geothermal heat pumps can prevent hindering water quality.

Policy Choices: Geothermal heat pump systems are applicable for residential and commercial heating and cooling, thus subsidies and financing can help incent the up-front investment in new construction. Furthermore, other subsidies and financing mechanisms can help deter the cost of retrofitting existing buildings. Public relations campaigns and product labeling help educate and inform consumers and businesses of the costs and benefits of installing geothermal heat pump systems. Right pricing of both water and energy helps provide the proper market signals for this effective but capital-intensive technology.

Groundwater pumping (possibly from coupled renewable electric sources):

Policy Objectives: Irrigation of crops using water pumped from aquifers has enabled tremendous gains in agricultural production by providing a secure medium-term supply. However, pumping groundwater faster than it is recharged turns the aquifer into a quasi-fossil resource that is not renewable and decreases long-term water security. Thus, groundwater pumping can increase or decrease water security depending upon the rate of pumping relative to recharge. Overdrawing an aquifer lowers the water table, which means more energy is required to pump that groundwater to the surface and a reduction in energy security and more GHG emissions from fossil power plants if the average electric grid delivers the electricity to the pumps.

Policy Choices: When groundwater is used for agricultural irrigation, the introduction of subsidies leads to increases in groundwater extraction. For example, irrigated agriculture in France and Spain has increased in response to subsidies for irrigation equipment and guarantees of low water prices [42]. Research models show that subsidies for water-efficient irrigation equipment, such as drip irrigation, are unlikely – contrary to popular belief – to reduce water use on a river basin level because optimal agricultural water application leads to higher crop yield and higher water consumption via evapotranspiration (ET) [43]. Higher ET coupled with zero return flows and decreased aquifer recharge lead to less water available for the entire basin [43]. Approaches to mitigating groundwater depletion include rules that prohibit expansion of groundwater pumping, such as the laws in place in most provinces in The Netherlands [42]. Proper scientific data collection and dissemination on groundwater levels are crucial for groundwater resource management, and some studies have shown that informing citizens of their water supply can influence their behavior. The use of information communication technologies can help inform regional and local water users on weather patterns, surface water flows, and groundwater levels such that they can informatively manage their groundwater resource.

Wind power, solar photovoltaic (PV) panels, and concentrated solar power (CSP, non-steam cycle):

Policy Objectives: Behind hydropower, wind power is often the most cost-effective renewable energy technology within good resource areas. Communities can often pool funding for community-scale wind power (one or a few large wind turbines) that focuses on serving local needs rather than feeding into the grid (but can also feed the electric grid). By providing locally-derived energy without consuming water during operations (aside from some blade washing), wind power enhances water and energy security without directly emitting GHGs. While typically more expensive, solar PV and concentrated solar power (CSP) systems that avoid use of steam cycles (e.g. Stirling engines) have the same GHG, water, and renewable energy benefits as wind power. Because of their size modularity for household-scale power and ability to operate off the electric grid in providing basic electric services, PV systems are usually the most easily deployable distributed renewable energy solution.

Policy Choices: Globally, wind and solar power have benefitted from subsidies such as feed-in tariffs and the production tax credit in the United States. Renewable Portfolio Standards that mandate a certain target installed capacity or percentage of total generation that must come from renewable energy technologies also provide medium to long-term certainty for investments in these capital-intensive systems whose benefits include the low operating costs. Because of this capital intensity, financing mechanisms such as Property Assessed Clean Energy financing [40] help reach residential consumers by spreading the costs of solar PV installation over time via property tax assessments. Wind and solar PV also stand to benefit by incorporating externalities such as water consumption and GHG emissions into markets and prices. Resource data gathered in renewable energy resource assessments help facilitate government and business planning to effectively develop projects in the most effective locations.

Combined heat and power (CHP) from biomass:

Policy Objectives: The use of 'waste heat' from thermal power plants and distributed energy generation systems for district heating and cooling makes more complete use of the fuel source to enhance energy security. Because less fuels are required for the delivered services of electricity, heating, and/or cooling (using techniques such as absorption chilling), less water is required for mining of those fuels and GHG emissions from fossil fuels are minimized per unit of energy delivered. CHP systems can use biomass and municipal solid waste for fuel such that localized and distributed concepts can be envisioned. CHP systems can include district heating and cooling such that community scale projects can enable distribution of energy in the form of hot or cool water. Furthermore, the collection of heat released from combustion can be used to desalinate low quality water resources to enhance local water security.

Policy Choices: While CHP technologies are readily available, policies are often necessary to incentivize the whole systems thinking required to minimize energy consumption for the infrastructure projects. Governments can provide incentives to capture waste heat from combustion of local fuels. Because energy costs generally already include full-cost accounting into their prices, right pricing should not heavily influence the use of CHP except in the event that new externalities (e.g. greenhouse gases) are included into energy prices.

Desalination:

Policy Objectives: Desalination systems enhance water security by providing potable and irrigation water from sources of high salinity. However, this process incurs large energy costs. Water quality is also detrimentally affected by having to dispose of the highly concentrated distillate byproduct. Because of the high energy inputs required, desalination adds pressure against carbon management due to associated GHG emissions from power plants and additional use of energy for water instead of displacing fossil plants. To avoid these GHG emissions, some project developers and governments choose to match distributed renewable energy systems with desalination [44, 45], and this solution provides an opportunity for those interested in attracting financing from sources such as the Clean Development Mechanism. Additionally, using waste heat (see Combined Heat and Power technology description) for thermal desalination of saline water can be a cooperative way to make use of energy resources to enhance water security.

Policy Choices: Because a reliable water supply is such a fundamental need for a good economy and lifestyle, governments can facilitate community engagement and subsidies for distributed energy and desalination projects. Properly pricing water supplies gives the correct signal for whether investment in desalination is warranted versus conservation and development of cheaper supplies. For regions where desalination is deemed a priority to mitigate fluctuations in water supply that occur over spans of decades, various financing mechanisms can help spread the costs over these long time frames. Operation and maintenance of filters and mineral collection and disposal systems present a challenge for operation in distributed situations.

Municipal waste and wastewater to energy:

Policy Objectives: By collecting methane gases from landfills and wastewater treatment plants (e.g. using anaerobic digestion), GHG emissions are reduced while a renewable combustible resource is created. Solid biomass waste can also be burned directly for heat and electricity. Additionally, the produced energy can power the wastewater treatment facilities making them self-sufficient, enhancing energy security, while they clean water for discharge into the environment.

Policy Choices: Landfills and wastewater treatment facilities are typically owned by municipal governments. Thus, household scale distributed energy waste to energy projects are less likely. New public works projects can incorporate the additional infrastructure required to capture energy, and retrofitting wastewater treatment plants is also possible. Financing associated with policies or a price on the externality of GHG emissions will likely make waste to energy projects more cost-feasible.

Greywater and reclaimed water use:

Policy Objectives: Greywater characterizes water after its use in applications that do not involve human or animal excrement (e.g. water from sinks, showers, dish washers, and clothes washers; water from kitchen sinks is not consistently included due to high organic content) [46-49]. After minimal treatment and filtering, greywater can be used in residential and commercial applications such as irrigation and sewage systems. While greywater is reused before using the full quantity of energy required to treat it back to potable condition, decentralized treatment systems are less energy efficient than large centralized systems. Research shows that greywater treatment uses approximately twice the energy per unit of water as pumping and treating sewage in a centralized system [41]. Thus, distributed greywater treatment and use enhances water security by recycling water but could decrease energy security.

Unlike greywater, reclaimed water makes use of treated effluent from centralized wastewater treatment plants. While this reclaimed water is generally not of sufficient quality to meet potable standards, it has undergone more treatment than greywater prior to being distributed in a piped network ("purple pipe"). With high existing levels of wastewater treatment and minimal distribution, reclaimed water use can reduce energy consumption while reducing freshwater demand for applications such as cooling systems for power plants, irrigation, and city wastewater plumbing. However, reclaimed water use coupled with less efficient wastewater treatment and significant distribution requirements can require more energy than it saves compared to conventional potable surface water treatment [50]. Thus, reducing water consumption via efficiency investments must be considered when analyzing reclaimed water reuse.

Policy Choices: Because it is important to keep potable and greywater flows separate for health reasons, greywater systems are usually confined to small scale residential and commercial use. For these separate residential and commercial applications, installed in new construction or retrofitted into existing homes and businesses, some fin

ancing assistance or subsidy can help overcome the up-front capital expense of integrating the system into the existing plumbing. Large scale municipal systems require additional treatment of wastewater effluent to produce reclaimed water before distribution in plumbing and sewer networks. Thus, significantly large-scale reclaimed water systems usually need publicly funded projects and financing to lay piping infrastructure that connects with buildings and homes. Additionally, clear regulations and plumbing practices help enable building contractors to properly design and install water reuse systems that safely connect to any available municipal reclaimed water systems. Right pricing of water, based upon quality, can help provide feedback to consumers and governments for making decisions about investments in greywater and reclaimed water infrastructure.

Chapter 3. Case studies of existing and potential policies and technologies for water resources management including distributed energy

1. Northern Mexico (Sonora and Baja California)

The state of Baja California Sur (BCS) is the least populated state in Mexico with slightly over 1 million people. Population density is low – the lowest in the nation – with over 2,400 settlements, only 17 of which are urban. Rural population in the state totals 78,000 people, 15% of state's total population [51]. Tourism is a major economic activity and is growing rapidly. Population growth, along with unsustainable agriculture, makes BCS a unique area for analyzing strain on the energy-water nexus.

BCS has the largest coastline (2,131 km) of any Mexican state and receives the least rainfall in the country. Water availability in BCS is very low – 1,070 m^3/yr on average – with the state capital of La Paz at 436 m^3/yr and the tourist city of Los Cabos at 701 m^3/yr. Many aquifers are over-exploited or experience salt intrusion and no state-wide water network exists; local water pipelines carry water from wells to distribution in urban centers. Slightly over 85% of homes in BCS have access to a water network, leaving over 70,000 without water access [51].

Energy systems in BCS are quite complicated. Unlike the rest of Mexico, BCS does not have ample gas and oil resources. Gasoline, diesel, and liquefied petroleum gas arrive by sea. While BCS is the only region in the country that is not connected to a national or international electricity network, over 95% of homes in state have access to electricity. The state electricity grid does not cover the entire state, particularly the north where small grids distribute electricity locally, translating to 20,000 people without access to electricity. Most electricity is generated using fossil fuels with a total installed capacity of 485.4 MW (474.8 MW from thermal, 10.0 MW from geothermal, and 0.6 from wind) [51].

Solar resources are abundant in BCS – averaging 5-6 kWh/m^2/day – reaching highs of 7 kWh/m^2/d in the summer and lows of 3 kWh/m^2/d in the winter [51]. Solar applications such as water pumping systems and solar lighting are used where electricity is not available. The U.S.-based Sandia National Laboratory manages the Mexico Renewable Energy Program is a partnership between the US and Mexico aimed at building markets for distributed renewable energies in rural communities that do not have access to the grid. In the 1990's, the Sandia National Laboratory estimated the market for solar-powered water pumping to be $2 billion USD.[52]

In addition to plentiful solar radiation, other renewable resources are present in BCS. Pockets of large wind resource potential exist in BCS, but the state as a whole is not generally windy. Average wind speeds are 2.6-6.2 m/s at 10 m above the ground surface. The northeast area of the state has four geothermal zones, including the 10MWe geothermal field in Las Tres Virgenes [51].

1.1. *Opportunities for new policies for distributed energy to alleviate water resource constraints*

Decentralized solar-powered and assisted desalination in rural arid regions

Mexico has enormous solar potential receiving an average of 5 kWh/m^2, and is as high as 7 kWh/m^2 in states close to the Pacific reach. The country's largest solar installations are in San Juanico (Baja California) and Agua Prieta Sonora, although solar technologies are still relatively nascent in Mexico. In 2006, 839,686 m^2 of solar collectors were installed for producing hot water. In the same year, 17.6 MW of photovoltaic modules were installed for rural electrification, communications, and water pumping. By 2013, 25 MW from photovoltaic arrays are expected to be online, which are estimated to produce 14 GWh/yr, or 0.01% of 2009 electricity generation [21].

Desalination is a common method of water treatment in BCS. A total of 67 systems are in operation, both state-managed and private, with 13 more under construction. Many private sector facilities exist to serve tourist populations. Of the 67 operating systems, 54 desalinate brackish water and 13 desalinate seawater using mostly reverse osmosis technology (four use multi-stage flash) with all systems using conventional sources of power. Sizes range from 2-1,998 m^3/d treatment capacity, totaling 16,971 m^3/d of installed capacity statewide. The desalination plant under construction in Cabo San Lucas will have a capacity of 17,280 m^3/d [51].

Despite the current reliance on conventional sources of power, some desalination facilities have worked to harness solar power. The first efforts to integrate solar power and desalination focused primarily on thermal desalination, with past projects in Puerto Chale in the 1970s, La Paz and Las Barrancas in 1980, and El Pardito in 1993. Current solar desalination projects utilize reverse osmosis technology, using solar PV arrays with battery banks to treat seawater. These current solar desalination installations can produce 19 m^3/d [51]. Reported benefits of solar desalination in BCS include providing electricity and clean water to communities without access to electricity or primary fuel resources or water networks. Economics, reverse osmosis membrane maintenance, energy recovery, and energy storage are concerns that limit implementation and performance of solar desalination systems [51].

Use of ICT for water resources management

Mexico allocates over 82% of its total water withdrawals for agricultural purposes. These withdrawals comprise 90% and 66% of total Mexican surface water and groundwater extractions, respectively. The Northern region of Mexico is one of the country's very productive agricultural regions despite the fact that its climate is desert-like and might only receive as little as 181 mm of precipitation annually [53]. Consequently, this area consumes a large relative and absolute quantity of available water for crop irrigation and is very susceptible to times of drought when there is not enough water to be distributed to all the users that need it. Overexploitation of groundwater reservoirs has thus become quite common (see Figure 15) as people pull unauthorized volumes of water from reservoirs that, by law, require concessions for extraction.

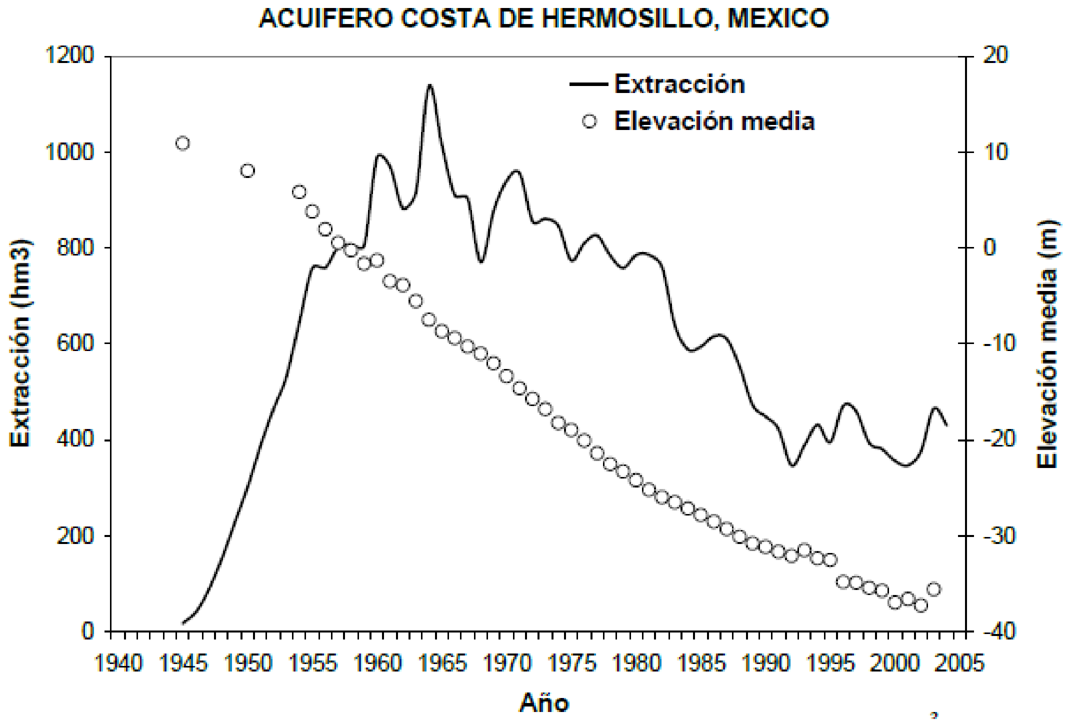


Figure 15. The withdrawal of water (y-axis) from the aquifer below Hermosillo has been much larger than its natural recharge over the last 60 years. The figure is unmodified from **[54]**.

The release of water from Mexican water reservoirs is controlled by the Mexican National Water Commission (CNA), but the use and distribution of this water is ultimately overseen by the Sociedades de Reponsabilidad, which are water user associations operated by farmers. The amount of water that is actually available for release is often less than the volume of water demanded by users and less than the volumes anticipated by the CNA. This disparity occurs partially because water rights are often rented from landowners over a year in advance, before it is known how much water will be available. Water quotas are allocated to landowners based on normal water use and can be rented to farmers at a price that reflects the profitability of their crop and the availability of water for delivery; thus, when shortages exist, those farmers with high-valued crops are usually given precedent over the water since they have paid expensive costs for insurance on water rights in the case that the original quotas cannot be distributed. Farmers who cannot pay the cost for insurance do not receive their anticipated volume of water determined by normal use quotas in times of low water availability [53].

Farmers in northwestern Mexico fall victim to a system in which there are few financial mechanisms in place to protect against reduced crop yields when there is not enough water available for irrigation. Below average inflows to water reservoirs in the Rio Mayo Valley in Mexico can reduce agricultural revenues as much as 35 to 40%. (Agriculture in this region is valued at $65 million). Northwest Mexico is located in a desert-like region making reservoir and water storage modeling difficult. Traditional insurance schemes such as that described above are financially backed by governmental subsidies and are thus expensive to run. They are also based on imperfect information which reduces their effectiveness. Reforms toward decentralization and market-oriented schemes have been made that have increased the role of water user associations, cost recovery, and has reduced water waste, but losses due to poor delivery infrastructure (evaporation and seepage) and inefficiency management still plague operations [53].

As the system stands today, many criticize that the Mexican government has not effectively aided the function of a market-based system, which they believe would mollify many of these issues. Although fees are levied on concessions to generate revenue to maintain water infrastructure, irrigation water is exempt. Since the government is then not able to collect fees on the majority of water withdrawals, there are not substantial funds to maintain well-functioning infrastructure. It is also difficult to monitor the uses of the country's many agricultural users, as there are so many that the CNA cannot keep up with processing concessions. The difficulty of monitoring many users enables unauthorized groundwater extractions. Aside from irrigators that choose to apply for concessions for subsidized electricity tariffs from the Federal Electricity Commission for agricultural pumping projects, many irrigators are able to draw groundwater illegally, as there are tens of thousands wells, even in small states. Some of the motivation behind subsidizing agricultural electricity is that irrigators apply for required concessions, rather than fly under the radar [9]. Many argue that if all illegal users were to apply for concessions, the CNA would not be able to process all of the concessions in a timely manner.

Implementing on-site measuring and control devices on wells would increase the ability of CNA, the Sociedades de Reponsabilidad, and irrigation districts to monitor, control, and govern water withdrawals in efforts to slow the decline of water tables. PLEIADeS (Participatory multi-Level EO-assisted tools for Irrigation water management and Agricultural Decision Support) is a project co-funded by the European Commission's Sixth Framework Programme within its Sustainable Development, Global Change and Ecosystems Priority that has been proposed as a tool to improve water management in the Sonora River Valley. It would provide real-time data on farm-level water consumption to that could be used to irrigation efficiency and stabilize aquifers.[55] Another program (SIRIUS = Sustainable Irrigation water management and River-basin Governance) is focusing on the Rio Yaqui and Rio Mayo irrigation districts. Remote wireless information communication technologies (ICT) and remote control technologies enable water managers to have accurate knowledge of water distribution to each of dozens of irrigation modules within each irrigation district. Groundwater wells can be operated remotely.

Thus, in the northern agricultural regions of Mexico, collecting data via remote and on-site ICTs is a major step forward. Using mobile technologies for collection of water storage, aquifer level, and river flow information can trigger water use restrictions based upon local and temporal conditions. These local responses can be governed by local preferences and customs to have 'buy-in' for water resource management. Because many sensing and valve stations would be in remote agricultural areas, distributed renewable technologies are well-suited for powering the ICT equipment.

By tying the control systems to weather predictions systems and satellite data, water basin management programs can make sure to only irrigate when necessary and anticipate dry and wet periods for short time scales (days to a weeks). For longer time periods (months to years) it is important to track major weather patterns such as the El Niño Southern Oscillation (El Niño and La Niña) and Pacific Decadal Oscillation as these events are major drivers of drought in Mexico upon which global climate change can potentially amplify impacts (recall discussion in Section 3 of Chapter 1) [27, 32, 56].

2. Mexico City

Seventy-seven percent of the Mexican population currently lives in urban areas, the largest of which is Mexico City – the nation's capital and political, cultural, educational, and financial center. Mexico City, with 20,450,000 people, is the third largest city in the world [20]. The Distrito Federal (DF) contains all of Mexico City's 16 delegaciones [57]; according to the Mexican Constitution, Mexico City is analogous to the DF, although the city has grown over the years. As a result, the entire metropolitan area is referred to as the "Metropolitan Zone of the Valley of Mexico," which includes Mexico City and urban sprawl into the neighboring State of Mexico [4, 57]. The Valley of Mexico Basin contains the DF and some or all of four different states, which includes more than 80 governmental bodies at the federal, state or local level.

The DF receives 948 mm of precipitation annually [57], which causes localized floods since the area is surrounded by mountains reaching over 5,000 m above mean sea level. Mexico City also has a large percentage of people living below the poverty line with 18% of its population classified as very low socioeconomic status and 67% as low-medium [4]. Thus, providing clean, affordable water and energy to this population is extremely important. Unfortunately an estimated eight million people in Mexico City do not have reliable access to the centralized water supply, as shown in Table 2, and those that do receive tap water from the City, question its quality, making Mexico the second largest bottled water consumer in the world. For many families, purchasing bottled water is their largest expense. People that lack access to the centralized water network are forced to spend an average of 6 to 25% of their daily income on 100-L water containers delivered by trucks. These people are typically the poorest, yet pay 500% more for water than those that receive the City's water [4].

Table 2. Access to water services in the metropolitan area of Mexico City, based on data from 1990 **[4]**.

	Total	Downtown	Municipalities in State of Mexico within the Metropolitan Area	Low-income settlements	High-rise buildings	Middle-income settlements	High-income settlements	Other
Number of houses without electricity	54 048	788	6814	40 461	3175	3598	704	329
Percentage of houses without electricity	1.8%	1.6%	2.7%	2.1%	0.7%	0.9%	1.1%	1.7%
Number of houses without sewerage	545 836	2247	96 010	398 218	23 707	17 122	8532	3249
Percentage of houses without sewerage	17.6%	4.5%	38.5%	21.1%	5.1%	4.4%	13.5%	17.2%
Number of houses without tap water	1 115 262	6486	133 878	872 222	61 026	36 341	5309	5932
Percentage of houses without tap water	35.9%	12.9%	53.5%	46.2%	13.2%	9.3%	7.8%	31.5%
Number of private houses	2 147 341	24 075	189 214	1 256 228	375 017	257 919	44 888	9996
Number of rented houses	678 956	20 837	40 903	448 443	53 788	104 927	10 058	5444
Percentage of private houses	69.2%	48.0%	75.7%	66.5%	81.2%	65.8%	76.0%	53.1%
Percentage of rented houses	21.9%	41.6	16.4%	23.7%	11.6%	26.7%	17.1%	28.9%

[a] Urban AGEB refers to geographical areas in settlements consisting of 2500 people or more (all municipalities are included even if population is less than 2500). Land use is for housing, industries, commercial, recreation or any other use, but not for agriculture, livestock or forest.
Source: Resultados definitivos. INEGI, Datos por AGEB Urbana, XI Censo General de Población y Vivienda 1990. Volúmenes del Distrito Federal, Estado de México e Hidalgo, 1992, in: CONAPO (2000).

Aside from water-scarcity, Mexico City's centralized water system is extremely energy-intensive and costly. Although the city was built on a huge groundwater aquifer, population growth and climate change have altered the hydrology of the region, forcing water-planners to look far outside the boundaries of the city to meet its needs. Currently the groundwater resources beneath the city can only meet 70% of the metropolitan area's supply. The remaining demand now is met by surface water reservoirs outside the periphery of the city in the Lerma-Balsas and Cutzamala river basins, which contribute 21% and 9% of Mexico City's demand, respectively. Water coming from the Cutzamala is pumped over long distances of up to 154 km, to elevations of over 980 m from the Cutzamala River to Mexico City [4]. It is estimated that this system consumes 1.79 billion kWh per year, which comes at a cost of 62.5 million dollars, annually. (To put this amount in perspective, it is similar to the total amount of electricity consumed by Puebla, a nearby state of 8.3 million residents.)[4] This figure is expected to grow as the Mexico Valley Aquifer and the Lerma Valley Aquifer, become more depleted.

In addition to Mexico City's energy-intensive water supply, the city spends a great deal of energy pumping water out of the city during flooding events. Ironically, as climate change has caused more intense droughts, it has also been linked to more frequent flooding, which overwhelms the city's feeble and relatively small sewer system [57]. Although a lot of effort and money has gone into flood infrastructure to drain water and wastewater out of the valley, this infrastructure has been largely ineffective for flood management. For example, in 2010, a major channel carrying wastewater effluent and excess rainwater from the city collapsed, displacing thousands of people and causing widespread concern over mosquito-borne diseases and other illnesses caused by the stagnant wastewater [12]. In rainy times, as many as 48 of the region's rivers flow directly into the sewer and as much as 70% of the total volume of wastewater might be rain [57].

2.1. Water infrastructure in Mexico City

Mexico City shares water sources, shown in Table 3, and water infrastructure with the 17 most populated municipalities of the State of Mexico. In 2002, 2.24 million m^3/d of water was supplied to the Metropolitan area from 374 deep wells (1.2 million m^3/d), 18 springs (0.071 million m^3/d to Mexico City only), and 97 other sources including snowmelt (remaining 0.96 million m^3/d) [4]. Water to Mexico City is distributed through a primary network of 1,074 km of pipelines (with diameters ranging from 0.5-1.83 m) and a secondary network of 12,278 km (with diameters less than 0.5 m). Mexico City infrastructure also includes 16 dams that have a total storage capacity of 2,827.9 km^3.

Table 3. Source of water to Mexico City **[4]**.

	Federal District (m^3/s)	State of Mexico[a] (m^3/s)	Total (m^3/s)	Percentage
Internal sources	20.0	25.2	45.2	68.5
Wells	19.0	24.8	43.8	66.4
Springs and rivers	1.0	0.4	1.4	2.1
External sources	14.8	6.0	20.8	31.5
Cutzamala	9.9	5.0	14.9	22.6
Lerma	4.9	1.0	5.9	8.9
Total	34.8	31.2	66.0	100.0
Percentage	52.7	47.3	100.0	

[a]Only municipalities which are part of the Metropolitan Zone of the Valley of Mexico.

In 2000, over 95% of the population of Mexico City had access to drinking water, either to a household or via a common community pipeline. The percentage of the population with water access in Mexico City is higher than that of the State of Mexico at approximately 84%, but the population nearly universally distrusts the City's tap water, making Mexico the second largest consumer of bottled water in the world [4].

The groundwater aquifers of the Valley of Mexico basin reside below Mexico City and serve as a domestic water supply, providing 70% of the water supplied to the Metropolitan region [4]. While the groundwater quality is relatively high due to low-permeability soil in the area, extraction is expensive and prone to unsustainable pumping due to low recharge. Pumping of the aquifers is currently estimated to be two to three times the natural recharge rate (45-54 m^3/s average annual withdrawal rate compared to 20 m^3/s recharge rate [4]) and has caused subsidence – now 0.4 m/yr – in the area since 1925 [57]. The Mexico City Metropolitan region extracts 1.7 times more water than what can be refilled by infiltration and runoff; extraction rates over 0.4 times refill rates are considered extreme by United Nations [57]. Falling water tables have closed some wells in central locations, but the aquifers have not been abandoned entirely.

Nearby surface water supplies are also used as water sources for Mexico City. The neighboring Lerma-Balsas river basin supplements groundwater supplies and provides 9% of the water delivered to the Metropolitan region [4]. Pumping of water from the Lerma-Balsas river basin began in 1951 as result of city subsidence and supply has been constantly declining since [57]. The Cutzamala System project, shown in Figure 16, was initiated after severe drought in 1974, to supplement additional water and now provides 21% of the water delivered to the Metropolitan region [4]. Original plans were to transport 64 m^3/s of water to Mexico City, but public pressure from Cutzamala Basin locals halted the project in 2002; only 15.1 m^3/s is now provided to Mexico City and the City of Toluca [57].

Water delivery to the DF is pumped from 60 to 154 km away, over elevation heights of 980 m [57], using 102 pumping stations, 17 tunnels, and 7.5 km of canals [4]. Energy consumption for such water delivery systems is substantial and likely to increase in the future as increasingly distant water supplies are needed to fulfill growing demands. The annual electricity requirements for water operations were estimated to be approximately 1.79 billion kWh in 2006 at a cost of \$62.54 million (not including water treatment and personnel). Of this total energy requirement, water operations, not including treatment or distribution from the water treatment plant to customers, require 6.05 kWh/m^3 on average. The total volume of water from the Cutzamala system alone to the treatment plant uses the equivalent of the energy that is consumed by the City of Puebla, with a population of 8.3 million people [4]. In 1992, an estimated 3.4 MMBBL of oil were required to pump, lift, and transport water from Cutzamala – 6% of the total energy budget for Mexico City [58].

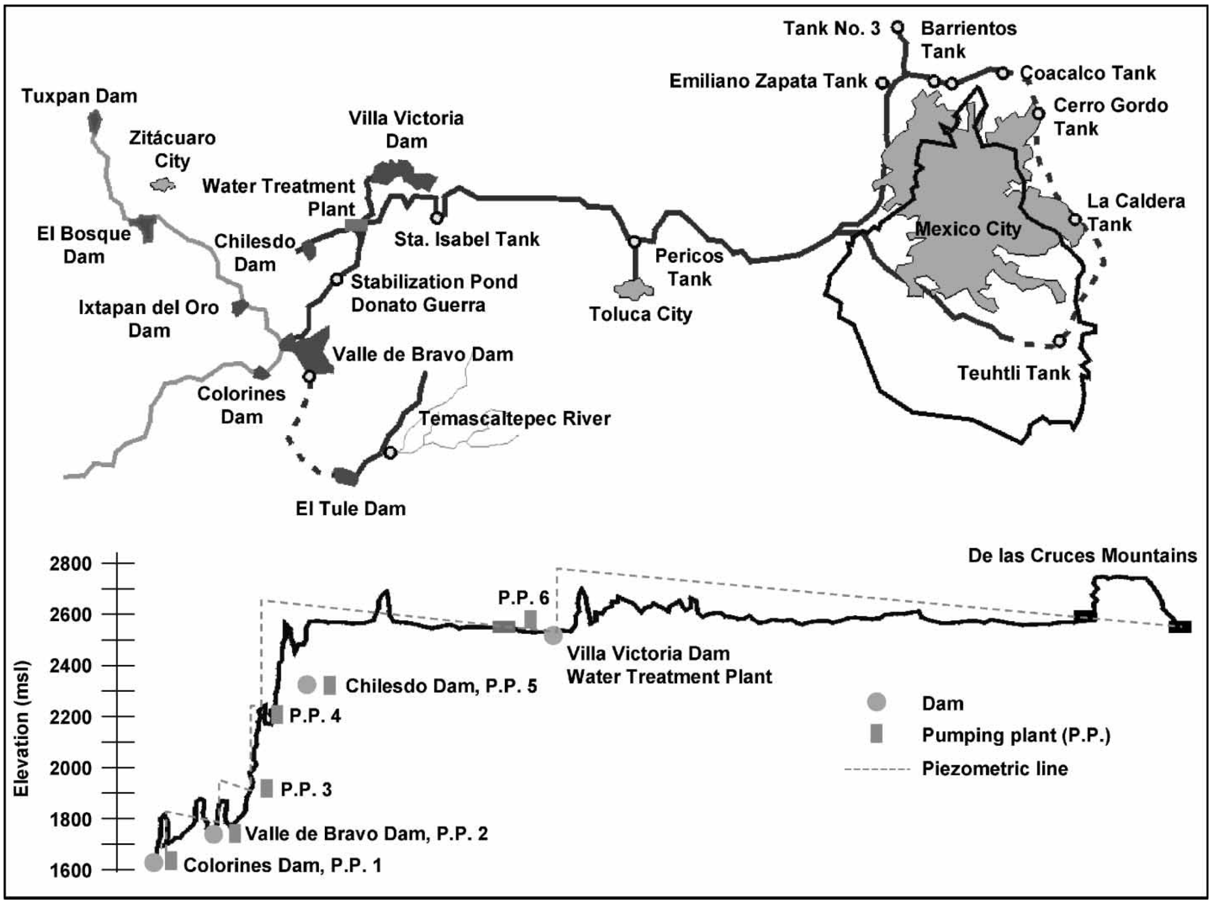


Figure 16. Water from the Cutzamala River Basin is pumped hundreds of miles (top panel), over large elevation gains (bottom panel) to supply the Metropolitan area of Mexico City [4].

Recent policy shifts towards decentralization of water management in Mexico City have exacerbated energy-water concerns. For example, little liability can be charged for the mismanagement of water resources, various stakeholders are not incentivized to fix infrastructure, and water concessions are difficult to enforce, among many other resource challenges. Infrastructure to handle the city's wastewater is lacking. New proposals to increase drinking water supplies via interbasin transfers are extremely energy intensive. Climate change is projected to increase drought, as well as flooding, which will increase the energy needed for water (for pumping, treatment, etc.) in the future.

2.2. Water management issues in Mexico City and the Metropolitan area

Mexico City suffers from a deficient water supply, yet flooding still occurs during the rainy season [57]. A large imbalance exists between water availability and use, as 84% of the GDP is represented in the central, northern, and northwestern regions where per capita availability is only 2,044 m^3/yr, whereas water availability in the southeast region is 14,291 m^3/yr but only represents 16% of GDP [4]. Despite significant investments to combat flooding for the past 400 years, floods still plague the area, and drainage and sewer infrastructure is ineffective [57]. The City's runoff is often more than the amount of surface water available for its supply, so many of the regions 48 rivers have their flow directed into the sewer. Depending on the season, 20-70% of wastewater might be rain [57]. Groundwater recharge and rainwater harvesting are two possible approaches to sustainable flood management.

José Ibargüengoitia from the Massachusetts Institute of Technology wrote a thesis in 2005 that analyzes the feasibility and efficacy of several decentralized water management options for addressing Mexico City's water crisis, with particular emphasis on recharge wells. This is a good resource to visit for a detailed analysis of the pros and cons of incorporating these technologies in the context of the Mexican political environment. One of his main conclusions was as follows.[57]

> "… [I]nfiltration basins require lots of land while trenches and resumideros are relatively cheap but their overall impact (pollution and recharge-wise) is more ambiguous. Recharge wells by contrast, seem to offer greater flow capacity, have in place structures that desilt the water and, due to their depth, can actually recharge the aquifer. However, they can be as much as ten times more costly than some of the other alternatives….Economic factors don't seem to offer much insight if they are not considered in conjunction with the central element of not having a well-developed infrastructure to deal with stormwater. It is not water scarcity, but infrastructure scarcity, manifested through flooding episodes, which drive the delegaciones' evaluation of the problem… Delegaciones found recharge wells useful to deal with flooding problems, even though they were originally presented as a unit for aquifer recharge."

Water supply and consumption rates are generally not well measured, so data typically vary by ±10% among different institutions. For example, water supply to the DF is between 32 and 35 m^3/yr, depending on source. Consumption in DF is approximately 343 L/capita/d, whereas other municipalities in State of Mexico consume 229 L/capita/d, including leakage [57].

Leaks also play an important role in Mexico City's water management, as water shortages are frequent. On average, a 10% deficit in water supply exists in Mexico City, which is exacerbated by high leakage rates since 35% or more of the water is lost to leakage in the core of the city [57]. These leakages represent 1,301 L/capita/d – enough to supply 4 million people. For those with intermittent or no water service, this water waste from high leakage rates creates unnecessary hardships as most people that rely on water purchased from trucks in 100-L containers. This purchased water typically costs 500% more than tap water sold to domestic customers, representing 6-25% of daily income [4]. In addition to social equity issues of water purchases, buying water from petroleum-consuming trucks represents an energy-intensive and inefficient method of delivering freshwater.

Mexico City's centralized supply-driven approach to water supply has not been successful. Unfortunately, decentralization of water management has been equally ineffective. Poor water quality, high levels of unaccounted for water, marked social inequity in terms of water access, and enormous water waste are problems that have plagued Mexico City [4]. With many stakeholders in many regions involved in water supply to the Mexico City Metropolitan area, water system accountability and efficiency are rare. Wastewater management is also very poor, with only one-third of wastewater in the DF receiving treatment before discharge to water bodies [57].

Current efforts by the National Water Commission are focused on improving water quality and maintaining water supplies. The Water Commission proposes to treat water from rivers that are eventually expelled from the Valley of Mexico Basin and use treated water for public consumption instead of exploiting groundwater. This water treatment approach is still in the planning stages. Groundwater recharge from stormwater runoff is another policy that could simultaneously reduce aquifer depletion and manage flooding [57].

2.3. *Greenhouse gas (GHG) emissions from Mexico City*

The Mexico City Metropolitan area is one of the most polluted areas of the world, mostly due to transportation emissions of greenhouse gases (GHG). Mexico's GHG emissions are roughly 2% of the global total, with 17% of national emissions coming from energy use in the Mexico City Metropolitan area.

Various policies exist to address air pollution. The Metropolitan Environmental Commission (CAM) published PROAIRE, its new set of policy and technological measures for addressing local air quality from 2002 to 2010. PROAIRE does not estimate GHG implications of policy since air pollution and GHG impacts are handled separately in Mexico, but it does include 89 institutional and policy measures that are not quantified [24]. Quantified metrics are investment cost and emission reductions for 5 local pollutants reported relative to baseline projection for 2010. While Mexico does not have a binding target for the reduction of GHG emissions, the nation does have an interest in reducing domestic emissions in order to attract foreign investment [24].

2.4. *Distributed technologies applicable for mitigating energy-water nexus challenges*

Distributed rainwater capture

In the past few years, decentralized rainwater harvesting (DRH) systems have offered a means of both supplementing strained water sources in times of drought and reducing pumping demand during times of flood. Since 2009, a non-profit called Isla Urbana has been installing distributed rainwater harvesting systems to bring non-potable water to families in Mexico City that would not otherwise have access to an affordable water-supply. As of June 2011, 521 systems, serving nearly 3,720 people have been installed. Although these systems cannot supply the entirety of a family's annual water demand, one system can supply, on average, about one-half of a family's water needs. The organization estimates that 50% of the City's residential water demand can be met by rain water harvesting systems if implemented on a large scale, which is equal to the volume water currently pumped into the city through interbasin transfers. (However, if commercial and industrial facilities are included, supplementing 30% of water demand with DRH might be a more realistic estimate.) [59] Furthermore, collecting rainwater at a large scale during the rainy season might also make an appreciable decrease in the amount of energy required to pump water out of the city during flooding. Less flooding might also reduce the risk of overflowing sewers, which can be harmful to public health when wastewater is released into the environment.

Rainwater harvesting in Mexico City is an example of how decentralized water management might placate the city's dire water situation. Today there exists a 10% deficit in the water supply; considering that 35-40% of the water entering the centralized water network is lost through leakage [4, 57] and the large contribution that DRH systems might have to the water supply [59], this is a deficit that can be placated with the necessary infrastructure improvements and public education campaigns.

Distributed solar energy via solar water heaters

One of the successes with Isla Urbana's rainwater harvesting installations has been its attention to educating the local workforce to install the systems, using local materials, and teaching families about the merits and upkeep of their systems. Integrating cultural considerations into the deployment of a new technology has proven critical to its success. This has been witnessed in the challenges that have faced the widespread adoption of solar hot water heaters (SHW) in Mexico despite the country's large amounts of solar radiation.

SWHs are renewable energy technologies that use available solar heat to warm a working fluid, which heats water in a heat exchanger and stores excess heat in a thermal store [60]. Two particular types of SWHs are distributed in Mexico City: plastic, possibly covered with glass, used to generate lower water temperatures, often used to heat swimming pools; and copper, aluminum, glass or other material tubes, often covered by glass or plastic, made to generate higher temperatures >30 °C on a large scale [60]. The most common style of SWH used in Mexico City includes an insulated tank integrated with the solar panel to keep water warm during cloudy and cooler days, but basic storage tanks and models with separate panels and insulated tanks are also available [60]. As seen from Table 4, because water heating accounts for over one-third of urban residential energy consumption, SWH can play a key role in providing water services with minimal energy consumption and no GHG emissions during operation.

Table 4. Fuel end-use in the urban residential sector in Mexico in 1990 [61, 62].

Final Use	GJ per capita	%
Cooking	3.20	44
Water Heating	2.75	38
Lighting	0.35	5
Appliances	1.00	13

The introduction of SWH installations in Mexico City had not been successfully integrated into the culture until 2007 when the Mexican Energy Commission released its *Programme to Promote Solar Water Heating* (PROCALSOL), which intends to triple the country's installed surface area of solar collectors by 2012. Although attempts had been made for over 30 years to markedly increase the deployment of solar hot water heaters, this policy was the first to successfully integrate the efforts of both private and public stakeholders across disparate disciplines such as manufacturing, finance, and government, to increase the rate of technology transfer to the public[63]. Also critical was a partnership with the German entity, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), who provided technical and regulatory advice to the Mexican government.

Despite stakeholder investment, there were a number of issues that contributed to the public's resistance to SWH prior to the advent of PROCALSOL. First, there were no standards for renewable energy technology such as SWH, making it very difficult for consumers to select a good system that would work for their particular needs. Systems were typically built by foreign companies, but sold by local distributors that had very little knowledge about the installment or operation of the systems. This typically resulted in faulty installations by the buyer, in which case the technology did not operate according to its specifications. Bad installations were typically not remediated since sellers were only present at the point of sale and offered no follow-up with the customer [60]. Thus, the local training associated with use of rainwater harvesting systems was not present for SWHs.

These issues were exacerbated by the fact that the Mexican culture generally has not embraced the environmental benefits of these systems, and therefore were not incentivized to buy systems that were a high-upfront cost. Many families also live day to day, so without financial incentives, those that did buy the systems usually chose the cheapest systems that were most likely to break or perform badly. Although there has been a large range of SWH technologies available in Mexico City for some time, without trustworthy information distributed by reputable sources, people had little incentive to spend money on a more expensive system. Even those who were aware of the merits of the SWH often were not inclined to make the large up-front investment because technologies with delayed rewards are simply not viewed as practical. Consequently, SWH in Mexico City had gotten a bad reputation among the general public, and therefore, have had difficulty gaining inertia despite their merits [60].

After the implementation of PROCALSOL, however, a number of these issues were mollified, which has significantly increased the uptake of the SWH technology and reduced the use of natural gas and petroleum for water heating. Public awareness campaigns have been launched to inform the public about the economic, environmental, and technological benefits of the systems. Training and certification programs, in tandem with rigid quality standards, were created to ensure high-quality installations. Training programs have been complimented with the creation of handbooks, training materials, and websites to inform buyers and sellers, as well as installers of SWH. All and all, these efforts, with the introduction of governmental voluntary standards, have significantly increased public awareness and utilization of the solar heating technologies[63].

A number of stakeholders are invested in SWH technology in addition to those mentioned above, including over 50 Mexican manufacturing companies, with 20 active companies in Mexico City and the surrounding regions [60]. A number of government officials at all levels are working on issues related to SWH technology, along with 3 universities in Mexico City [60]. Other stakeholders include non-governmental organizations and consultancy firms like the National Association for Solar Energy [60].

Chapter 4. Financing of distributed water and energy infrastructure

1. Greenhouse gas and renewable energy policy in Mexico

As Mexico's population and economy grows, so too does electricity demand. The increase in energy demand is far outpacing population growth; while population is growing at a rate of 0.8% per year, current electricity demand is growing at 4.4% a year [21]. In the year 2050, national electricity consumption is estimated to reach 900 TWh annually with the largest regions of growth are in tourist regions, such as the Yucatan and Baja California Sur. Three million people in Mexico still lack access to electricity. Most of these people live remote regions, where electricity infrastructure is still limited, or in some cases non-existent. Distributed renewable energy sources might be an effective means to provide electric power to those people who have not been able to have it in the past [21].

Mexico has an environmental climate that is extremely favorable to renewable energy generation. In particular its solar resources are among the strongest of any region on the earth. In fact, due to its large land-mass and location in close proximity of to the equator, Mexico receives more solar radiation than any other country in the world. Temperatures in Mexico typically range between 15-26 °C on average. Mexico is also situated in a region of great tectonic and volcanic activity, which contributes to the country's vast geothermal potential. Wind resources in the country, especially in regions along the coast, are ideal for wind generation. In particular, the Isthmus of Tehuantepec, has extremely strong and consistent winds due to the currents in the Gulf of Mexico and the Pacific Ocean [21]. Finally, Mexico's lakes and fast moving rivers have contributed to its sizable hydroelectric generation capacity, which will likely grow, especially as more small-hydro projects are developed.

In 2008, Mexico generated 3.9% of its electricity from renewable electricity sources (excluding large hydropower generators). The country made a goal to increase its renewable generation share to 4.5% by the year 2010, and 7.6% by 2012. Wind generation is projected to make up well over half of non-hydro renewable generation, with geothermal providing another quarter. Small hydro, biogas, and biomass are projected to provide the remainder of this target [64]. Solar energy, which is still considerably more expensive than other forms of generation, has yet to make a significant contribution to electricity generation.

In 2002, Mexico's carbon dioxide (CO_2) emissions were the 12th highest in the world. The electricity sector accounts for one-third of CO_2 emissions and 55% of sulfur dioxide and nitrogen oxide emissions. Of total CO_2 emissions, oil contributes 60% with coal and natural gas constituting the bulk of the remainder at 22% and 17%, respectively. The majority of sulfur dioxide emissions originate from oil (79%), with coal contributing the remainder [21].

Mexico's future renewable energy goals include the reduction of CO_2 emissions by 6.3Mt/yr due to renewable energy installations in the public sector. Private sector planned renewable energy installations are expected to reduce emissions by an additional 3.52 Mt annually. The total 2012 CO_2 emissions reduction is estimated to be 3.9Mt from renewable energy sources generating 12,500 GWh/yr from 3,600 MW capacity [21]. The Undersecretary for Energy Planning and Technological Development estimates GHG reduction potential to be 81 million t of CO_2

equivalent annually; at \$12.13/tCO_2, revenues would be 983 million dollars from Clean Development Mechanisms from the Kyoto Protocol. Obstacles to achieving these emissions reductions include production and investment costs, lack of incentives and financing mechanisms to start large-scale installations, and lack of industrial capacity and qualified workers on existing projects [21].

2. Financing and expenditures for water and renewable energy in Mexico

2.1. Clean Development Mechanism (CDM) in Mexico

CDM projects are activities that those Annex-I[4] countries that have signed the Kyoto Protocol can fund in developing nations (non-Annex I countries). These CDM projects offset Annex-I domestic emissions to comply with their Kyoto Protocol emission reduction targets. These activities are intended to allow Annex-1 countries to meet their reduction targets at a lower cost, while transferring knowledge and technology to lesser-developed countries so that they might develop more sustainably.

The main recipient countries for CDM projects are China, India, Mexico, and Brazil. The majority of Mexico's renewable energy generation to date has been due to the fact that it has become a popular host country for CDM projects, not due to Mexico's own policy making.

As of April 2011, Mexico has 249 CDM projects of varying scope, completed or under development (see Figure 17) [65]. The average CDM project size in Mexico is 70-80 kt CO_2 equivalent (CO_2e)/yr, and the median CDM project size is approximately 20 kt CO_2e/yr [65]. A total of 152 of these projects were manure methane avoidance projects, which will collectively offset 5,370 kt CO_2e per year and provide 790 MW of electricity generation capacity when all projects are complete. Twenty-four of the CDM projects were wind installations that will collectively add 2.5 GW of capacity to the country's electricity grid and avoid 5,520 kt-CO_2e per year in emissions. A total of 29 landfill gas projects will collectively offset 3,290 kt-CO_2e per year and add 152 MW of electricity generating capacity. In total current CDM projects in Mexico have the potential to offset nearly 19 Mt-CO_2 per year and add 5.1 GW of electricity generating capacity.[66]

[4] Annex-1 countries are those developed nations and nations with economies in transition that are part of the Convention of Parties of the United Nations Framework for the Convention on Climate Change.

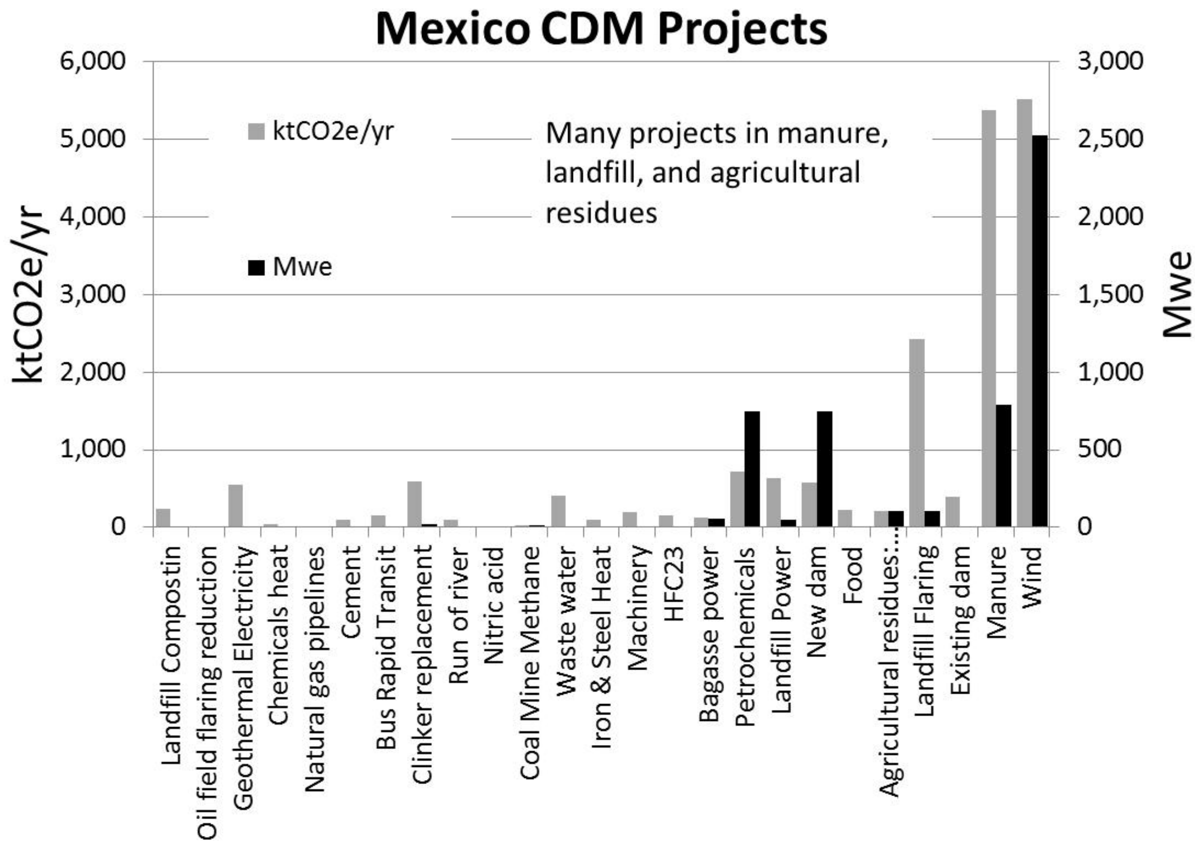


Figure 17. A summary of CDM projects within Mexico indicates that wind farms and manure projects are the most attractive for project development due to the available resources in Mexico and the ability to provide energy while reducing GHG emissions [66].

Despite its strong renewable resources, Mexico's domestically driven renewable energy development is hindered by high-initial start-up costs. Some policies have been incorporated into Mexico's regulatory framework to promote the adoption of renewable energies; however these policies have yet to make an appreciable impact on the adoption of new policies. In Guadalajara, Monterrey, and the Central Valley, biofuels blending mandates have been instituted. In Mexico City, net metering for solar photovoltaics (PV) is being incorporated in efforts to incentivize distributed solar PV technology [64].

Overall the Mexican culture has not yet embraced the environmental arguments that have driven other nations to increase renewable generation. Its renewable energy targets, thus, have largely been an attempt to attract foreign investors that might invest in clean energy projects or establish new industries in Mexico in a less-polluted environment [24]. One other major driver is the country's concern over reduced petroleum output, which has greatly affected its bottom line [21]. Growing electricity demand is also a major concern for this country, whose oil revenues are a crux of its economy. Although natural gas has become a larger part of Mexico's electricity generation mix (870 trillion BTU consumed) over the last decade, it still consumed 430 trillion

BTU for electricity from of petroleum in 2008 [17], a significant portion of its domestic oil production. Burning petroleum products to produce electricity is one of the least efficient and most costly forms of electric power generation. With growing worldwide demand for oil, growing electricity demand within Mexico, and declining Mexican oil production, Mexico will face difficult decisions regarding the consumption or exportation of oil. Mexico's oil available for export will continue to shrink if substitute forms of electricity generation are not pursued. As of 2010, Mexico consumes 2.1 million barrels of oil per day and produces 3.0 million barrels per day (MMBBLd), down from a peak production of 3.8 MMBBLd 2004 [17]. Mexican oil exports dropped to 1.3 MMBBLd in 2009 from 2.1 MMBBLd in 2004, significantly decreasing the potential revenue to the government during a time of rising oil prices. Renewable energy deployment and energy efficiency can be extremely important in Mexico's future by offsetting oil consumption for electricity and helping preserve the country's valuable oil for international trade.

2.2. Household expenditures on water and energy services

In considering the ability of various financial mechanisms to assist in installing distributed renewable energy systems for assisting with the provision of water in Mexican households we review information on the current pattern of household expenditures, the willingness to pay (WTP) for improved water services, and the full cost of installing and operating the renewable and/or water systems. Studies of developing and rural areas note that charging consumers the full cost of recovery for renewable energy systems often does not work because the full costs are beyond the income levels of the rural populations [39]. In thinking of electrification of rural areas to improve or begin electricity services, it is important to consider the existing level of other prerequisites for sustainable development, such as clean water. There is a need to understand how the existing conditions of existing water and energy services in a household play a part in determining the value to those households for new distributed renewable energy projects.

According to the National Household Survey of Income and Expenditures (Encuesta Nacional de Ingresos y Gastos de los Hogares – ENIGH) performed by the Instituto Nacional de Estadística y Geografía (INEGI) on average 22% of Mexican household expenditures go to pay for food, beverages, and tobacco. Any bottled water purchases are likely included in this amount. The average household pays 6.6% of its expenditures for household maintenance, electricity, fuels, and water services delivered to the household might be under this category. Thus, it is unclear from the ENIGH data how much is paid for water service to households.

Surveys of households' willingness to pay (WTP) for improved water services in developing countries have indicated they are willing to spend from 2-9% of household income [67-69]. A survey of residents in the mid-sized urban area of Hidalgo del Parral, in Chihuahua, Mexico indicated that less than 18% of households drink tap water (presumably untreated) [68]. More than 63% of those Parral households treat tap water in some form: approximately 35% of households use water filters, 21% boil tap water, and 13% treat tap water with chlorine. The authors report that almost 81% of households report consuming bottled water as a substitute for tap water. On average, those households consume 51 L of bottled water per week amounting to a monthly median household expenditure on bottled water of 108 Mexican Pesos ($M), or 9 $US compared to 158 $M/month (14 $US/month) on expenses for tap water (filtering, storing, etc.) to improve water service. These water expenses are for a city with median annual household income of 3,040 $M (260 $US) [68]. Thus, approximately 8-9% of household income was spent on the provisioning of drinking water.

Data from the Instituto Nacional de Estadística y Geografía (INEGI) [70] indicate that the median Mexican annual household income is between 1,930 and 2,400 $M. See Table 5. Thus, the area of Parral has a higher median income than does Mexico overall. For the low income deciles the percentage of household expenditures for the food, beverage, and tobacco expenses (29-37%) plus the home maintenance, electricity, and fuels (8-9%) total to a range of approximately 37-46% of total expenses. Much of the funding for development of distributed renewable energy for improved water services can potentially originate from these budgets to provide better water services.

Table 5. Mexican household expenditure data by decile for 2008. The expenditures for Mexican households show that approximately $US 189 electricity, and fuels. Approximately 22% of household expenditures go toward food, beverages, and tobacco of which we can consider water purchases to be a subset [70].

		Household Decile									
	Totals	I	II	III	IV	V	VI	VII	VIII	IX	X
Number of Households	**26,732, 594**	2,673,259	2,673,259	2,673,259	2,673,259	2,673,259	2,673,259	2,673,259	2,673,259	2,673,259	2,673,259
Expenditures of households (1000s of pesos)	**1,022,875,133**	17,826,168	29,585,797	39,709,196	49,407,891	60,190,011	74,719,309	93,175,116	118,256,686	165,775,447	374,229,513
average income per household (pesos)	**38,263**	6,668	11,067	14,854	18,482	22,516	27,951	34,855	44,237	62,012	139,990
average income per household ($US @ 11.7 USD per peso)	**$ 3,279**	$571	$948	$1,273	$1,584	$1,930	$2,395	$2,987	$3,791	$5,314	$11,997
% of total Mexican household income	**100.0%**	1.7%	2.9%	3.9%	4.8%	5.9%	7.3%	9.1%	11.6%	16.2%	36.6%
% of total expenditures for food, beverage, tobacco	**22.2%**	37.1%	34.2%	31.2%	30.5%	29.2%	28.0%	25.9%	22.8%	20.6%	13.1%
% of total expenditures for housing services of maintenance, elec., and fuels	**6.6%**	7.9%	8.8%	8.7%	8.3%	8.2%	7.6%	7.3%	6.6%	6.5%	4.9%

Soto Montes de Oca and Bateman (2006) reported various levels of WTP for improved water services by surveying households in three different income areas of urban Mexico City [69]. Relatively wealthy households were more willing to pay for investments that maintained the current level of water service as they already received a relatively high level of service. Less wealthy households were more willing to pay for investments that improved water services because they have lower quality of existing service. In fact, 91% of low income households (3,088 peso monthly income) reported consuming bottled water in the home versus 61% of higher income households (5,981 peso monthly income) in a different neighborhood. In addition to drinking more bottled water, the respondents in the lower income neighborhood reported worse water service for four other measures of water quality: low water pressure, poor water quality (cleanliness, smell, color, taste), frequency of water shortages, and storing water in cisterns. Thus it seems poorer urban residents receive worse water services while they simultaneously have to spend a higher percentage of a lesser income to obtain clean and reliable water.

Future research and surveys may need to get to the core issue of why water pressure is low in poor neighborhoods. Is this because electricity for pumping is unavailable? If so, then renewable energy technologies could play a role in providing that electricity. If low water pressure is due to leaking pipes, then renewable technologies will likely not help the problem much unless locally stored water is pressurized by local pumps. This localized use of pumps can become quite costly and energetically consumptive [41] whereas gravitational solutions for flowing water (collected from roofs or from centralized systems) from stored tanks will reduce the need for electricity.

The range of incremental WTP (that over current water bills) for "maintaining" the status quo level of service was 225-257 pesos bimonthly whereas the rage of WTP for "improving" the level of water service was 280-301 pesos bimonthly [69]. The mean WTP incremental values were 164% and 197% of the current water bills for the maintenance and improvement scenarios, respectively, as defined by the authors [69]. These WTP values represent 5.2% and 6.4% of household average income, or 8.4% and 9.5% of average household income when adding the WTP to the existing average water bill. Thus, this survey suggests households are willing to almost double their expenses for water service, and future research could explore the reality for any real infrastructure projects.

When translating the WTP into total money in paying for water infrastructure and service one can take the WTP multiplied by the number of households to estimate possible sources of revenue to pay off investments. Approximately 2 million households were estimated to be in the Mexico City survey areas discussed in Soto Montes de Oca and Bateman (2006). They noted that the income level of the household was significant in both preferring the maintenance scenario over the improvement scenario (at high incomes) and having a higher WTP. Thus, by associating the WTP to different income groups (those with certain levels of income) the authors estimated the total revenue for water infrastructure investments. By summing the factor of "(WTP for a given income group) x (income group population)" the authors calculated approximately 4,000 million pesos per year (~ 360 million $US). In using an equity weighting scheme, where lower income groups are given more weight because of their increased potential to gain welfare from improved water services, 5,000 and 7,300 million pesos (~ 450-650 million $US) were estimated available for the maintenance and improvement scenarios, respectively.

However, these estimates for total willingness to pay were larger than the revenues collected, but near the same quantity of revenues plus subsidies. Thus, there seems to be the possibility to improve water services, charge these urban customers, and reduce subsidies [69].

There exists a research opportunity to consider overall energy and water solutions that involve combinations of technologies and policies to enable users to financially handle the up-front costs of distributed energy and water infrastructure. Some of the technologies for investment that can be considered are:

- Distributed rooftop photovoltaic solar panels
- Distributed or community scale wind turbines (up to multi-megawatt scale)
- Rainwater collection gutters and storage cisterns
- Water filtration equipment and pumps
- Solar hot water heaters
- Geothermal heat pump systems
- Solar distillation of saline water supplies

For targeted regions within Mexico, future research can explore if the costs are minimized by integrating these and other technologies into a comprehensive sustainability solution for water provision versus investing in the technologies and infrastructure individually [71]. Community projects can integrate renewable and water infrastructure while also teaching and training the local stakeholders to maintain and operate the equipment. For instance, a project that integrates wind and solar power to pump, treat, and distribute or store water is useful as long as it remains functional. But replacing filters or fixing electronic equipment may not be straightforward. Thus, trained personnel might be needed that live in or near the local community.

ICT can be used to provide knowledge and feedback on the current conditions of local water resources. In this way local communities can be empowered to 1) understand their local environment, 2) interact with government agencies by using scientifically collected data, and 3) be part of solutions for water resources management. The case study of Sonora and northern Mexico agricultural areas indicates that there are opportunities for ICT projects to help educate local citizens for making efficient irrigation decisions.

2.3. Financing (and microfinancing) and 'water funds' for up-front costs and project development

Although decentralized electricity options have a number of distinct advantages, they also suffer from certain unique disadvantages, important among which are their high initial investment costs that are generally borne by single households and the intermittent nature of electricity or heat supply from them. As a result, their contribution to rural electrification has faced its own distinct hurdles [72]. However, "Rural electrification is economically justified only when the emerging uses of electricity are strong enough to ensure sufficient growth in demand to produce a reasonable economic rate of return on the investment. Rural electrification may be in a unique position to promote a paradigm shift in agricultural production, by making irrigation possible …" where it is otherwise not possible due to the need for electric pumps [72].

As additionally noted in [39]:

> "It is also important to note in this context that all modern renewable energy technologies share a particular characteristic that often limits their use by poor people: They have high initial capital costs and low recurrent (fuel) costs relative to fossil fuel-based technologies. This is particularly so for photovoltaic electricity, hydropower, and wind energy. The poorer the people, the less likely it is they can afford this kind of renewable energy. For this reason, poorer people often pay more per unit of energy used simply because they cannot afford the initial costs of supply options that have the lowest lifetime cost. Similarly, where generating utilities have very severe limits on capital expenditures, their opportunity cost of capital at the margin rises to very high levels. They will then commonly opt for technologies with a lower initial capital cost, such as diesel generators, over an apparently preferable renewable option, such as micro hydropower."

Furthermore, "Experience during the past 25 years demonstrates that at the heart of the problem of developing decentralized energy supply options are the very high costs associated with putting together the various elements of technology, finance, community development, and management required to make such schemes work" [39].

Even in relatively wealthy urban neighborhoods in developed countries, obtaining the money for up-front costs of solar photovoltaic panels is prohibitive. Aside from direct subsidies, financing concepts such as property assessed clean energy (PACE) have been created to alleviate this problem. PACE programs generally involve bonds sold by local municipalities that are paid back by distributing the cost of the renewable energy infrastructure to property taxes of the households that have the renewable energy installations. In this manner, if the homeowner sells the house, the cost of the renewable energy system is passed to the next owner via higher property taxes. Thus there remain questions as to how this PACE concept could be applied to lower income areas in developing countries. We see the investigation of PACE-like financing mechanisms as a potentially important avenue for future research for distributed water, rainwater collection networks, and renewable energy infrastructure in Mexico.

Another similar financing concept for renewable energy and water infrastructure could be microfinancing. Microloans generally amount to less than the equivalent of one hundred US dollars. Some research has shown that it might be possible to use microfinancing as a way to pay for water services infrastructure [73]. A survey study of Indian "slums" by Davis et al. (2008) [73] indicated that 60% of respondents were interested in taking a loan to improve access to a water sanitation system (toilet), a connection to a city water supply, or both. The amount of microloan proposed in the surveys amounted to one to two months of salary paid off over the course of 1.5-2 years. Because water infrastructure can be installed simultaneously to serve more than one household (e.g. trunk pipeline with capacity for many households), it is likely that multiple households within an area would need to form a collective group such that their combined loans are enough to pay for some infrastructure improvement. The Davis et al. (2008) study did indicate that forming these collective groups was the primary reason cited for a lack of will to pay for improved water services described. The reason is that each member would be partially responsible for collectively paying off the loan if one member fails to do so. Persons that had already obtained a loan within the past five years were more likely to accept the microloan concept. Thus, it might be beneficial to make sure that collective loan groups include a business owner or person who has already acquired a loan in the past. Additionally, microloans could be provided to train and equip local skilled workers for installing and maintaining distributed water and energy infrastructure.

There are other financing models for sustaining water supplies that do not focus upon distributed renewable resources, but are applicable in many regions of the world. One of these mechanisms is the establishment of water conservation funds. Water funds combine private and state contributions to help protect the watersheds around urban areas. Some global organizations, such as The Nature Conservancy, are promoting water funds in many cities and regions in Latin America including Bogotá, Colombia and Quito, Ecuador. Initial seed funding for these water funds can create the collective network to generate millions of dollars needed to protect local watersheds[5]. For example, The Nature Conservancy fund in arranged in Quito, Ecuador started with $10,000 in 2000 before attracting investment from U.S. Aid for International Development and local partners. With payments from the people of Quito, the fund is used to protect the quantity and quality of the water from the watershed that supplies Quito with 100% of its water supply.

There could be equivalent water or "water-energy" funds established to maintain aquifer recharge zones and river watersheds as well as establish solar water heating systems and collect urban runoff from cities and rural areas within Mexico. Opportunities exist to create the stakeholder networks for Mexican water funds, specifically around Mexico City. Organizations such as The Nature Conservancy have had success because of their ability to use the fund for multiple missions (e.g. watershed protection for municipal water supply, plant and animal species biodiversity and protection) that attract a wide array of interested parties including from local residents and businesses to international companies and organizations. Expanding these funds to link water and energy could be a new twist to enhance both urban and rural development.

[5] See stories: http://www.nature.org/ourinitiatives/regions/latinamerica/water-funds-of-south-america.xml; http://green.blogs.nytimes.com/2009/11/26/water-funds-proliferate-in-latin-america/;

Chapter 5. Conclusion

1. Summary of key findings

Analysis of the energy-water nexus in Mexico reveals some important conclusions regarding the use of renewable energy for water systems. While many opportunities exist for the coupling of renewable energy and water systems, a few key aspects of integrating resources are highlighted here:

- *Solar hot water heating can reduce fuel use when appropriately implemented.*

  While use of SWH in Mexico City was not successful for many years, the government and industry learned the following lessons from these failed attempts and greatly increased SWH deployment after the implementation of PROCALSOL. Vast solar resources and domestic hot water needs translate to a suitable environment for SWH. When systems are reliable, technologies are explained to customers, support is readily available, and up-front purchase costs are subsidized, SWH can easily penetrate the market. Focusing on policies and public education regarding SWH can greatly increase installations.

- *Affordable financing is essential for technology adoption.*

  In a country with a significant percentage of the population below the poverty line, affordable interest rates over sufficient loan terms are vital for adoption of new technologies. High capital costs are often the largest barriers to implementation of renewable energy technologies, especially with regard to water supply. Decreasing the burden of financing can help the expansion of new technologies.

- *Understanding a customer's ability and willingness to pay is important.*

  There appears to be the willingness to pay for improved water services, and many people are likely already spending more than necessary. Poor people in Mexico, and developing countries worldwide, spend a large percentage of household income on energy and water services. When tap water is of questionable quality, many people spend 500% more than domestic rates for the purchase of bottled water from trucks. This water supply mechanism is inefficient both in terms of energy and money. Considering both a customer's ability and willingness to pay for energy and water services can change the economic feasibility of a project. Appropriate pricing for energy and water services is also a social equity issue, especially considering those without access.

- *Fresh ideas for water and energy conservation can make large strides.*

  Thinking outside the box regarding water conservation can dramatically decrease water waste and help maintain water resources. Reducing or stopping leaks in Mexico City could produce a water supply sufficient for 4 million people. Implementing widespread rainwater harvesting could decrease flooding as well as the energy for pumping stormwater, while also serving as a water supply for many without water access.

Harnessing solar power with distributed PV arrays can deliver electricity to populations not connected to the grid and power water and wastewater treatment systems in areas without such access. The creation of water funds can be used to purchase land or restrict certain land uses for the maintenance and preservation of water resources for both quality and quantity (aquifer recharge).

- *Information communication technology (ICT) can be an effective means of education.*

  ICT enables the collection and transmission of important data regarding the status of natural resources. Measuring, recording, and transmitting data on streamflow, water quality, aquifer levels, solar radiation, wind speeds, air temperatures, lake and reservoir levels, flood stages, and drought conditions can educate the researchers, policymakers, and other stakeholders. Collecting important data is the first step to understanding and sustainably managing natural resources because the data provide objective information about which to have participatory stakeholder discussions. With this understanding, ICT can also facilitate broader education of the public via television or radio broadcasts, fostering a sense of value for the conservation of resources. ICT technologies can also relay information from broader global information networks operated within other countries.

2. Areas for future research

Many opportunities exist for future research on developing renewable energy technologies for water supply. In particular, we propose the following areas of focus:

- *Willingness to pay for water and wastewater services*

  Understanding the percentage of household income spent on water and wastewater services is important for assessing the willingness to pay for improvements [67, 73]. Normal assumptions suggest that utilities typically consider 5% of household income for water and wastewater services as the limit [67], but this percentage can be much higher, especially in poor populations. Local surveys to gather information on water services desired and the willingness to pay or get a loan for such services [73] could greatly inform policy and management decisions.

- *Using renewable energy and ICT to facilitate participatory networks for water resources management*

  Placing the costs for renewable energy technologies and ICT in the context of the distribution of household expenses and government budgets could help facilitate technology adoption. Furthermore, integrating renewable energy with ICT can aid data collection and decision-making. ICTs enable objective data collection and presentation that can facilitate participatory networks that bring stakeholders together to best provide water services for disparate needs such as potable municipal water, irrigation, and aquifer maintenance and protection. Because water-related issues are specific for each geographic location, research into how to best collect and present accurate information on water use and resources is always an opportunity.

- *Economic analyses of coupling renewable energy with water services*

  Analyzing the economics of coupling renewable technologies with water services in the context of a local environment is important for overall feasibility. Non-monetary factors, such as aversion to a particular technology, might influence the adoption of certain technologies. Consequently, targeted economic analyses are necessary to determine appropriate subsidies or incentives to encourage adoption.

- *Statistical analyses of project success in terms of technical complexity*

  Installing technically complex water or energy solutions in rural communities can be an unsustainable practice when the technology is poorly understood. A statistical analysis of the technical complexity of a solution and the length of time it operates would help convey how well technology can be maintained by rural communities. This sort of analysis could reveal the ramifications of installing distributed renewable, high-technological solutions in areas without experienced people for repairs and maintenance or quick access to replacement parts.

- *Role of microfinancing and water funds*

  Understanding the importance of collective group loans and microfinancing to overcome up-front costs for water infrastructure and renewable energy installations (such as photovoltaics or solar water heating) is important for distributed technologies. Studies could determine the ability of water funds to maintain sufficient pervious cover regions and groundwater recharge zones and maintain wetlands that provide ecosystem services related to water filtration and aquatic habitat. Teaming up with national and global organizations can help raise money and awareness for water funds. The Nature Conservancy pilot study in Quito, Ecuador, could be used as a guide for Mexico City or areas that need water recharge.

- *Understanding discretionary spending for different cultures*

  A comparison of different country-level statistics on the percentage of household income (or expenses) allocated toward basic needs could help inform planning and management. Relating household total income/expense level and GDP (or GDP per capita) could lead to a better understanding of appropriate pricing for water and energy services, along with suitable investments in renewable energy technologies. Results from this work could assess discretionary income (approximately total income minus spending for water, transportation and/or liquid fuels, food, and electricity) to investigate the human development pattern associated with general income and reliable and clean water service. Understanding the distribution of household spending on electricity, water, and discretionary expenses could lend insight into cultural adoption of sustainable technologies, especially for projects that could reduce household expenses in the long-run.

3. Addressing research areas

Different approaches might be appropriate for addressing our selected research areas. For example, quantifying a particular culture's discretionary spending and willingness to pay for water and wastewater services could be best achieved via personal surveys and focused primary research with targeted populations. On the other hand, understanding the potential role of microfinancing would be best achieved via pilot-scale investments with focus groups to determine feasibility. The former examples represent areas where more primary research is needed to fully understand the nature of implementing renewable energy technologies for water supplies, while the latter is an area where development interventions could fill a gap. In general, the science behind using renewable energy technologies for water supplies is better understood than the human elements of cultural acceptance and technology aversion. Focusing research in combined scientific and sociological contexts would increase the likely success of development projects. Development interventions are likely best suited for circumstances where economic factors represent the main hindrance to adoption of mutual energy and water solutions.

Acronyms

CAM	Metropolitan Environmental Commission
CAN	Comision Nacional del Agua, National Water Commission
CDM	Clean Development Mechanism
CFE	Federal Electricity Board
CHP	combined heat and power
CONUEE	National Board for the Efficient Use of Energy
CRE	Regulatory Board for Energy
CSP	concentrated solar power
DF	Distrito Federal
DRH	decentralized rainwater harvesting
DTR	diurnal surface temperature range
EIA	U.S. Energy Information Administration
ENIGH	Encuesta Nacional de Ingresos y Gastos de los Hogares, National Household Survey of Income and Expenditures
ENSO	El Niño Southern Oscillation
FEC	Federal Electricity Commission
GHG	greenhouse gas
ICT	information communication technologies
INEGI	Instituto Nacional de Estadística y Geografía
KMZ	Ku-Maloob-Zaap, one of the largest producing oil fields in Mexico
LAWRE	Law for the Exploitation of Renewable Sources
LFC	Central Power and Light
LFI	large foreign investors
MBR	membrane bioreactor

MFC	microbial fuel cell
PACE	property assessed clean energy
PLEIADeS	Participatory multi-Level EO-assisted tools for Irrigation water management and Agricultural Decision Support
PR	public relations
PV	photovoltaic
SAGARPA	Secretaria de Agricultura, Ganaderia, Desarrollo Rural, Pesca y Alimentacion, Secretary of Agriculture
SEDESOL	Secretary for Social Development
SENER	Secretary for Energy
SIRIUS	Sustainable Irrigation water management and River-basin Governance
SWH	solar hot water heater
WTP	willingness to pay

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