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The Carbon Abatement Potential of Rainwater Harvesting in Mexico City

Throughout the country of Mexico, water management issues are worsening because of increasing population, lack of sanitation and clean water, and a tendency to invest in expensive infrastructure. Also, as a signatory to the Kyoto Protocol, Mexico must play its part in reducing greenhouse gas emissions. The purpose of this paper is to explore rainwater harvesting as a strategy to reducing carbon emissions and as a means for providing Mexico City with a more sustainable water solution.

At the beginning of the twentieth century the boundaries of Mexico city were confined to the north-central area of the federal district of Mexico (Distrito Federal, D.F.) However, Mexico City has grown so much that the urban footprint now fills the borders of the D.F. and goes beyond them crossing into the State of Mexico and even reaching as far as the state of Hidalgo. Thus, when one refers to Mexico City, the name can be ambiguous as to whether one is referring to the city within the boundaries of the D.F., that is Mexico City proper, or to the conurbated area around Mexico City, which goes beyond the borders of the D.F. and is termed the metropolitan zone of Mexico City (Zona Metropolitana de la Ciudad de Mexico, ZMCM). The ZMCM is one of the fastest growing urban centers in Mexico. (SEDESOL, 2004; Tortajada, 2000)

No one government organization is responsible for water supply, distribution and wastewater collection in the ZMCM. The responsibility is instead shared by the municipal government of Mexico City, the government of the State of Mexico and the federal government. (Tortajada 2000) For the purposes of our study, we have restricted our focus to Mexico City proper, that is Mexico City within the political boundaries of the D.F.. Within

Mexico City proper, the municipal water agency, La Sistema de Aguas de la Ciudad de Mexico, (SACM) is the primary government agency that manages water and wastewater for its residents. The National Water Commission (Comisión Nacional del Agua, CONAGUA), which operates on the federal level, is responsible for the "delivery of water in bulk to the ZMCM, for operation of many of the deeper water supply wells, and the operation of various aspects of the hydraulic works dealing with importation of water from neighboring basins." (National Academy, 1995)

Mexico City water users rely primarily on the water network (RED) that runs throughout the ZMCM to supply them with water. The primary network is 870 km of pipelines and a secondary network of 10,600 km. (Tortajada 2000) However the RED is inefficient and unreliable and its supply of water is unsustainable.

Water for the ZMCM comes primarily from the Valley of Mexico aquifer. (CONAGUA, 2010a; Tortajada, 2006)The aquifer is currently being overexploited. The rate of withdrawal from the aquifers is significantly higher than the recharge rate: 45 m^3/sec is abstracted but the natural recharge rate is only 20 m^3/sec, leaving an over-exploitation of 25 m^3/sec. (Tortajada 2000) As a result of this overexploitation, the water table is decreasing. The soil that Mexico City is built on is soft clay and the shrinking of the water table causes the clay soil to consolidate, resulting in regional land subsidence. (National Academy, 1995) The amount of soil subsidence in Mexico City can reach as far as 9 meters in certain parts of the city. The subsidence has worsened the issue of flooding. It also damages the pipes in the water network (being one of the causes of leaks) and other city infrastructure.

As a testament to its inefficiency, over 30% of all the water that goes into the RED is lost because of leaks. (National Academy, 1995) The amount of water lost through leaks would be enough to provide 4 million people with water. The government repairs about 4000 leaks in the network every month. (Tortajada 2000)

Water for the ZMCM is also brought in from distant river basins. The two in particular are the Lerma-Balsas river system and the Cutzamala system. The Cutzamala system is very energy intensive. Water from the Cutzamala system is transferred over a distance of more than 60 km and must then be pumped higher than 1000 m, which requires 102 pumping stations. The amount of energy that the Cutzamala requires to operate on an annual basis is equal to that of 16.5 million barrels of oil. This amount of electricity is equivalent to the amount of energy used by the city of Puebla that is inhabited by over 8 million people. (Tortajada, 2006)

Almost 3% of the population in the D.F. does not have access to the water network (CONAGUA, 2010b) and while 97% have some kind of access to piped water, only 74 percent have an in-house source. (National Academy, 1995; Tortajada, 2000) For some residents, especially the poorer ones, despite access to the RED, service can be intermittent with some users reporting service only twice weekly. Some also face shortages, especially during the dry season. (Lankao, 2010) The neighborhoods where the water supply is intermittent or completely lacking are concentrated in the eastern and southern portions of the city. (Sosa, 2010; Tortajada, 2000)

To address their lack of water, many residents will purchase tanker trucks called PIPAS. PIPAS are large diesel run trucks that can carry as much as 16 m^3 of water, but more often 8 m^3. These trucks can either be run as a part of a government service or as a privately run service. Most fill up with water from the RED (although some rely on private wells) and then transport the water to residents who need it. They can be bought at market rate, but some users receive partial or full subsidies from the municipal government. In 1994, poor people buying water from PIPAS were paying 500 times more than registered domestic consumers. (Tortajada, 2000)

Water problems are not the only environmental issues that Mexico City is grappling with. In 2008, the Mexico City government released a climate action program that outlined the city's strategies for reducing GHG emissions, adapting to climate change and addressing the city's host of other environmental problems. The report included estimates on how much the different strategies would cost and how much of a reduction in GHG could be expected from the particular strategy. An entire section of strategies is devoted to water sustainability initiatives. Among the water initiatives, rainwater harvesting is not included.

(SMA, 2008) This study seeks to provide estimates of the carbon abatement potential of rainwater harvesting to provide policymakers with information on this sustainable source of water.

Rainwater harvesting (RWH) is a practice that is thousands of years old. It involves collecting rainwater and storing it for later use. Rainwater can be harvested for agricultural, domestic, industrial and other uses. (Helmreich, 2009) In the context of this paper, we will be looking at rooftop rainwater harvesting primarily as a means of providing water for public uses.

In its fourth assessment report, the IPCC featured RWH as a means for adapting to climate change. While this study acknowledges the role that RWH can play as a sustainable climate change adaptation strategy, the purposes of this study is to explore RWH as a mitigation strategy for reducing greenhouse gas emissions. (IPCC, 2007) Within this context, a report published by the National House-Building Council (NHBC) and Environment Agency of the UK found that "buildings using harvested rainwater or treated greywater typically increase greenhouse gas emissions compared to using mains water." However, that report considered only a subset of rainwater harvesting methods. The NHBC report looked at a RWH direct feed system where any time a user wanted water, a pump would have to be activated. A direct feed system is more carbon intensive than a header tank system where water is delivered to a header tank which then distributes water to a household by gravity. Also, the reported considered the embodied energy costs of the storage tank and pump and did not take into account the reduced demand from the main municipal water system. For this study, the RWH system in consideration are different from those looked at in the NHBC report.

In Mexico City, the majority of households (>50%) already have a storage tank/cistern, pump and header tank. (INEGI, 2010) For our study, we will only consider the carbon abatement potential RWH systems installed in these households. In terms of embodied energy, the NHBC study found that the construction of the storage tank and pump were the most significant contributors to the carbon costs of RWH systems. In the Mexico City context, because the majority of households already have this infrastructure installed, the embodied energy associated with installing a RWH system in these households is negligible.

Methodology

Equation

To estimate how much carbon can be abated by a rainwater harvesting system, we compare how much carbon is released annually without the RWH system (baseline emissions year) with the amount of carbon released annually with a RWH system (project emissions year). The difference between these two amounts is the potential emissions reductions.

$$ER_y = BE_y - PE_y$$

Where:

ER_y	Potential Emissions Reduction ($MtCO_2e$)[1]
BE_y	Baseline emissions in year y ($MtCO_2e$)
PE_y	Emissions as a result of project installation in year y (Mt CO_2e)

For our study, we consider the two primary means a resident can obtain water in Mexico City: through the water network, the RED; or from tanker trucks, PIPAS. Both of these ways of supplying water release carbon. The RED releases carbon indirectly by relying on electricity to power its pumps. PIPAS release carbon because they fill up with water from the RED and they also release carbon from burning diesel in their engines to transport that water. The rainwater harvesting method we look at in this study collects rainwater from rooftops, filters it and then channels it into existing cistern. This process does not release carbon.

In this model, there are two fundamental sources of carbon emissions: carbon emissions resulting from electric energy consumption and carbon emissions from fossil

[1] $MtCO_2e$ stands for Metric Tons of Carbon Dioxide Equivalent.

fuel combustion. The RED only emits carbon as a result of electric energy consumption. PIPAS emit carbon both from electric energy consumption and fossil fuel combustion.

To calculate the level of emissions in the baseline and project year, we separate the emissions into two groups based on the sources of water. In other words, emissions that resulted from water arriving to a user via the RED is one set of emissions and water arriving via PIPAS is another set of emissions. To calculate the level of emissions in the baseline year, we add together the emissions that result from using the RED and the emissions from using PIPAS.

$$BE_y = E_{BL,RED} + E_{BL,PIPAS}$$

Where:

$E_{BL,RED}$	Emissions released by the *RED* in the baseline year ($MtCO_2e$)
$E_{BL,PIPAS}$	Emissions released by the *PIPAS* in the baseline year ($MtCO_2e$)

To calculate the emissions that result from using the RED, we first establish the amount of emissions released per liter of water from the RED. We then multiply that by the amount of water that is being used by the RED in the baseline year. This gives us the amount of emissions released in the baseline year from using the RED.

The emissions released from using the RED are the result of the use of electric energy. Electric energy is used to pump water from their sources: the aquifer, the Lerma system and the Cutzamala system. Once the water has been drawn from their sources, electric energy is used again to pressurize and deliver it throughout the water network.

$$E_{BL,RED} = ERU_{RED} \times W_{BL,RED,y}$$

Where:

ERU_{RED}	Emissions released per unit of water delivered by *RED* ($MtCO_2e/L$)
$W_{BL,RED,y}$	Water delivered by *RED* in the baseline year (L)

We use a similar process for calculating the level of emissions released in the baseline year from using PIPAS. Calculating the emissions released in the baseline year from using PIPAS is a two-step process. The first step involves the emissions released as a result of using the RED to fill the PIPAS. The emissions that result from filling a PIPA are the result of electric energy associated from using the RED. The second step involves the emissions released from delivery of that water by the PIPAS. PIPAS are large tanker trucks powered by diesel. Diesel combustion emits carbon. To find out how much carbon is emitted by using PIPAS, we multiply the rate of carbon emitted per kilometer traveled by twice the distance from the PIPAS filling station to the delivery site (we multiply by twice the distance to account for the PIPAS return trip after it has delivered the water). We then add the result from this step to the previous one and come out with the total amount of emissions released in the baseline year as a result of using PIPAS.

$$E_{BL,PIPAS} = ERU_{PIPAS} \times W_{BL,PIPAS,y} + n_{PIPAS}(EF_{CO2,FF,y} \times 2 \times d_{ps\rightarrow \mathrm{home}})$$

Where:

ERU_{PIPAS}	Emissions released per unit of water from filling the PIPAS ($MtCO_2$/L). Because PIPAS fill up with water from the RED, $ERU_{PIPAS} = ERU_{RED}$
$W_{BL,PIPAS,y}$	Water delivered by PIPAS in the baseline year (L)
n_{PIPAS}	Number of *PIPAS* a household uses in a year.
$EF_{CO2,FF,y}$	Emission factor for fossil fuel used ($MtCO_2$/km)
$d_{ps\rightarrow \mathrm{home}}$	Distance traveled from *PIPAS* filling station to home. (km)

For the project year, the emissions released per unit of water delivered by the RED and PIPAS remains the same. However, what is different is water demand, as we expect demand from the RED and PIPAS to decrease because in addition to those sources, water is also being supplied by a RWH system that is more carbon efficient. The water provided by the RWH system offsets the need to use the RED and PIPAS. Because a RWH system can provide water without creating additional emissions, it is not included in the emissions equation for the project year.

$$PE_y = ERU_{RED} \times W_{PJ,RED,y} + ERU_{PIPAS} \times W_{PJ,PIPAS,y}$$

Where:

$W_{PJ,RED,y}$	Annual water delivered by *RED* after project has been installed (L)
$W_{PJ,PIPAS,y}$	Annual water delivered by *PIPAS* after project has been installed (L)
$ERU_{PJ,PUMP}$	Emissions released per unit of water pumped from cistern to tinaco after *RWC* system has been installed($MtCO_2$/L)
$W_{PJ,TOTAL,y}$	Annual water consumption after project has been installed (L) $W_{PJ,TOTAL,y} = W_{PJ,RED,y} + W_{PJ,PIPAS,y} + W_{PJ,RWC,y}$

Parameter Values

To calculate the emissions released per liter of water used by the RED, we used an estimate based on the total water consumption and total electric energy use by the water network in Mexico City. According to government records, Mexico City used 1,123,194,611 m^3 of water in 2009. (CONAGUA, 2010b) According to estimates provided by the SACM, the amount of electric energy consumed in 2009 for the purposes of extracting water from the aquifer and pumping it through the water network were 478.4 GWh. (Gutierrez Wood, 2012) Water for the RED also comes from the Cutzamala, which is operated by the National Water Comission, CONAGUA. The Cutzamala system in 2009 provided Mexico City with 244.60 hm^3 of water and provided the neighboring state of Mexico with 155.38 hm^3 of water, thus in total providing 399.98 hm^3 of water. The provision of the 399.98 hm^3 of water consumed 1,135,976,290 kWh of electric energy in 2009 according to CONAGUA's records. (Calderon Rodarte, 2012) Because only 244.60 of the 399.98 hm^3, or 61.1% of all the water delivered by the Cutzamala went to Mexico City proper, we cannot include the 1,135,976,290 kWh consumed in total amount of electric energy used by the Mexico City water network. If we assume, however that the electric energy consumption is proportional, then we can multiply the proportion of water that is going to Mexico City, 61.1%, by the total energy consumption and by doing this we arrive at 694,684,235.5 kWh which is an estimate for the amount of electric energy consumed by the Cutzamala system to provide water to Mexico City. Thus, the total amount of electric energy consumed by the RED in Mexico City is 1,173,084,236 kWh. Using this, we find that the ratio of total volume 1,123,194,611,000 L to energy consumption, 1,173,084,236 kWh is 0.001044418. Thus the RED uses approximately 0.001044418 kWh per liter of water it delivers.

For the emissions factors regarding electric energy consumption, we relied on information published by the International Energy Agency. In their international statistics report for 2011, Mexico's energy mix produces 455 grams of CO_2 per kilowatt-hour. (IEA, 2011) Thus, for our calculations, we assume that for every kilowatt-hour of energy used in Mexico City, 455 grams of CO_2 are released. This, in combination with the energy to volume ratio we found earlier, tells us that approximately 0.475210014 grams of carbon dioxide are released per liter of water provided by the RED.

ERU_{RED}	0.475210014 (grams CO_2/liter)

For the emissions factors regarding the burning of diesel fuel, we relied on estimates provided by the United States EPA. PIPAS are tanker trucks that either have an 8 m^3 or 16 m^3 capacity. The more common variety are the 8 m^3 tanker trucks, which will be the only ones we consider for this study. In terms of vehicle classification, a payload of 8 m^3 classifies these trucks as medium heavy-duty trucks. To estimate the emissions of these diesel burning medium heavy duty trucks, we used the EPA 2010 standard which is 247 grams CO_2/ton-mile. (EPA, 2011) Transporting 8 m^3 of water per trip works out to an 8.8 short ton payload, and thus, a PIPA emits approximately 1353 grams CO_2 per km.

$EF_{CO2,FF,y}$	1353 (grams CO_2/km)

PIPAS typically fill up with water from the RED. Thus, in addition to the emissions released as a result of using diesel tanker trucks to deliver the water, there is an associated release of emissions as a result of using the RED.

$ERU_{PIPAS} = ERU_{RED}$	0.475210014 (grams CO_2/liter)

The amount of carbon abated in our study is based on the reduction in demand for water from the RED and PIPAS. To calculate volume of water that can be collected using RWH depends on the precipitation event and the catchment area: one millimeter of rainfall on one square meter produces one liter of water. Because our estimates are done on an annual basis we multiply annual average rainfall data by the roof area. That should give us the potential volume of water that can be collected by the system. We then multiply this number by a discount rate of 75% to account for user error and for uncollected, small-scale precipitation events that are not captured by the RWH system.

Worked Examples

Now we consider the expected emissions reductions from three different example cases. Because the exact emissions reductions per building can only calculated on a case by case basis, these examples are meant to explore the potential emissions reductions possible in different cases. In each example, we assume that total water consumption is the same both before and after the installation of a RWH system. In our first two examples, we will also assume that a PIPA truck travels 10 km from its filling station to its household. The emissions reduction is also based on a conservative estimate of the lifetime of a RWH system of 10 years.

Typical Household

In this example, we consider a household that receives water from the RED, but faces a water shortage about four times throughout the year. Water service from the RED is at its most unreliable during the dry season and thus, most water service shortages occur during this period. Water service that does not meet user demand is more common for households in the southern and eastern regions of Mexico City. Those areas tend to be less affluent. (Sosa, 2010) To make up for the shortage, the household in this example purchases PIPAS.

As mentioned earlier, the potential volume harvested from a rainwater harvesting system depends on the size of the catchment area, which in this case is the roof. Because larger roofs have more area to collect rainwater, we expect a greater volume of water harvested from systems installed in households with large roofs. The more volume that can be collected from a RWH system means that less water is needed from the RED. Because shortages in water tend to occur during the dry season when rain is sparse, we assume that a RWH system cannot offset entirely the need for PIPAS and can only reduce the need for them somewhat. In this example, we assume that the installation of a RWH system reduces the annual need for PIPAS from 4 a year to a minimum of 2 a year. Figure 1 presents our estimates for the potential abatement possible by varying roof size. As expected, larger roofs means a greater amount of carbon abated because less water is being used from the RED.

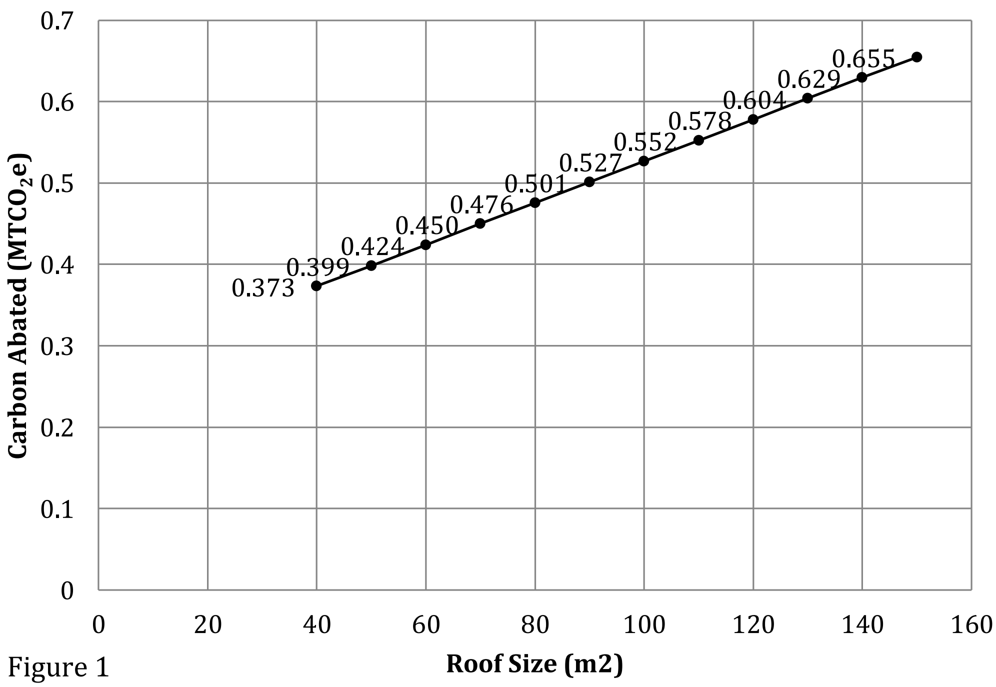

Figure 1

PIPAS Only Household

In this example, we consider a household that receives water exclusively from PIPAS. This is the case for as much as 3% of Mexico City households that don't receive water from the RED. For this household, we assume that prior to the installation of a RWH system, the household required 12 PIPAS a year, which works out to 96,000 L of water annually. Rainwater harvesting can only provide water during the rainy season. So during the dry season, the household will have to return to using PIPAS. We take this into account by assuming that at a minimum, a family will purchase 6 PIPAS and possibly more if the RWH cannot completely meet their needs during the rainy season. Figure 2 presents our estimate for the expected emissions reduction after installing a RWH system.

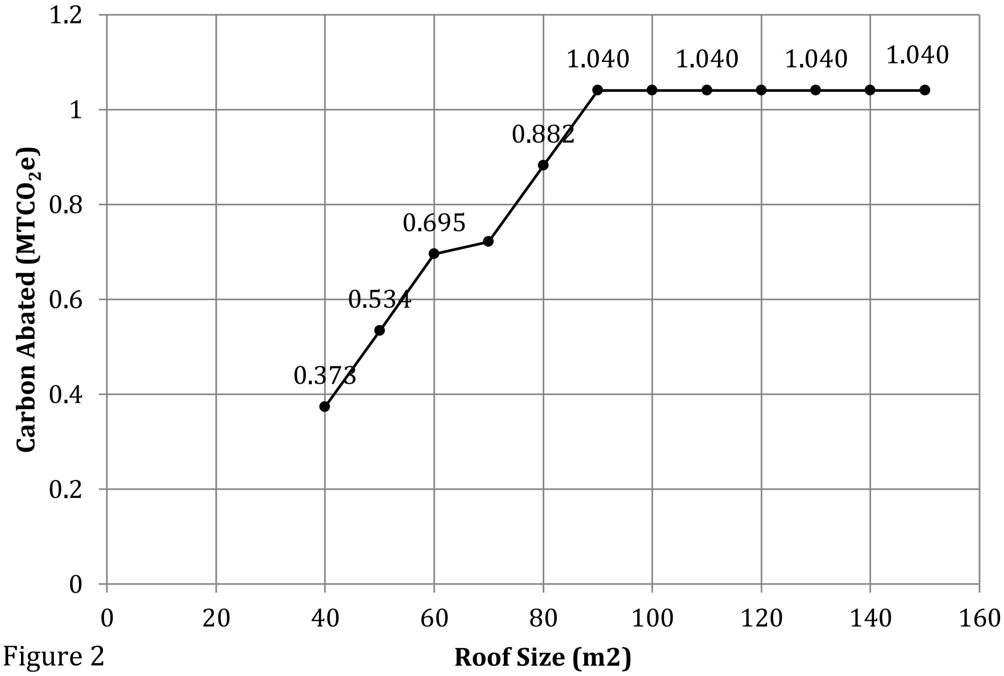

Figure 2

Again, larger roofs mean a greater abatement because larger roofs can collect more water. We see greater abatement of carbon in this example compared to the typical household example because the RWH system is offsetting PIPAS, which are more carbon intensive than the RED, which is the primary source of water for the typical household. At a certain point though, roof size becomes irrelevant since the RWH system collects more water than the household can use during the rainy season. That water does not contribute to any carbon abatement since the household will still need to purchase 6 PIPAS for the dry season when there is no rain.

Large Roof Buildings

The last example we consider are buildings with a large amount of roof space—buildings like large retail stores or warehouses that cover a large amount of surface area. The amount of rainfall that can be collected from these buildings is significant. From a surface area of 10000 square meters (about the size of a typical big box store) it is possible to collect more than 5 million liters of water annually. In our example of large roofed buildings, we do not include PIPAS in our consideration and instead only consider the emissions reducing potential of RWH system coming from displacing the use of RED water. Figure 3 shows our estimates of the expected potential emissions reductions.

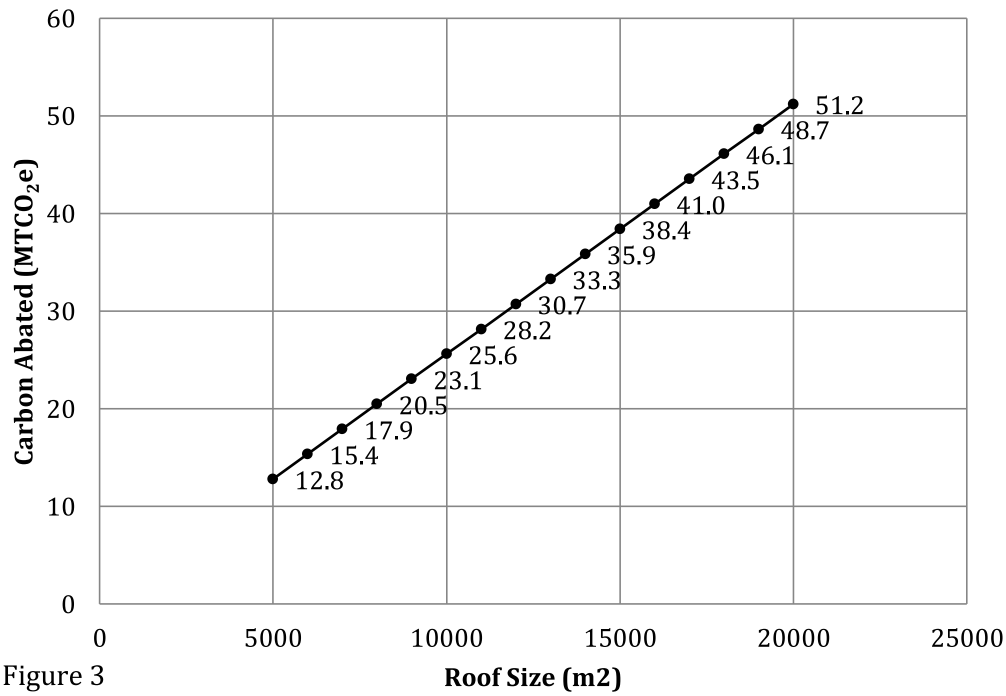

Figure 3

Case Study: Isla Urbana

In this section we consider the work of Isla Urbana, a project of the International Renewable Resources Institute (IRRI), which is based in Mexico City. Isla Urbana's goal is to facilitate the widespread adoption of rainwater harvesting. Isla Urbana trains and works with local plumbers to install systems in Mexico City households. Isla Urbana uses only local materials and works with its beneficiaries to train them on the maintenance and use of their system. (Isla Urbana website) As of August, 2012, Isla Urbana has installed approximately 1000 systems, with more added every day. Figure 4 illustrates the effect on carbon abatement that Isla Urbana has.

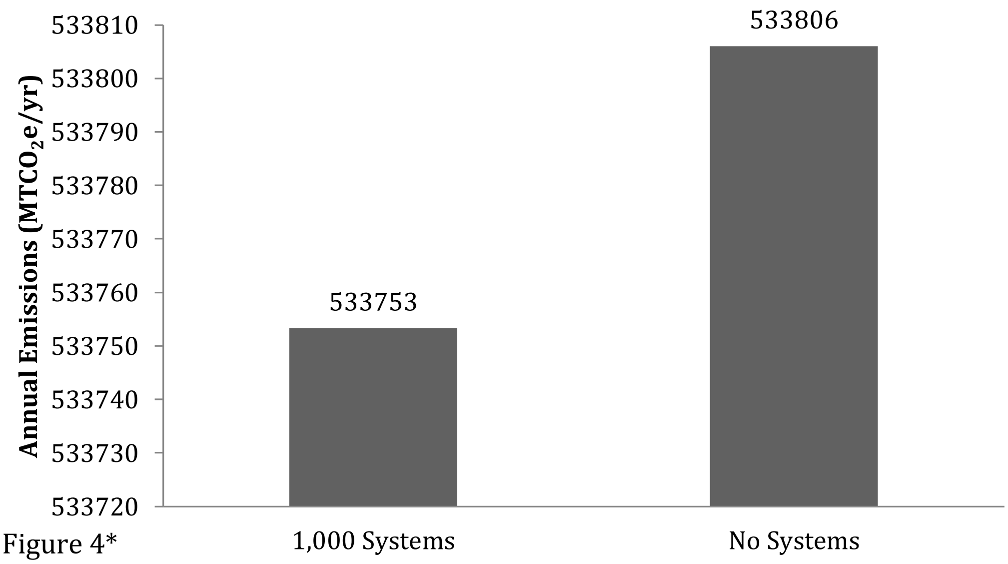

Figure 4*

The first bar represents the annual emissions from the electricity consumption of the Mexico City water grid in 2009. The second bar represents the expected emissions if Isla Urbana had not installed 1000 systems. Isla Urbana's RWH systems decrease water demand from the Mexico City water grid, thus we expect emissions would have been higher had Isla Urbana not installed any systems.

Table 1* Project	Cost (millions of pesos)	CO_2 Emissions Reductions ($MTCO_2e$)	Abatement Ratio (Pesos per ton of $MTCO_2e$)
Sustainable Housing Initiative	845	3351	252000
Improvement of RED's pump control system to avoid unnecessary equipment use during low demand hours	321	5000	64000
Energy improvement of RED's water pump system equipment	3671	19000	193000
Installing 1.2 million RWH systems	6000	63240	95000

* Isla Urbana has installed rainwater harvesting systems in households of varying roof sizes. For figures 4 and table 1, one system represents an annual abatement .0527 $MTCO_2e$, which represents the abatement rate of a household with a roof size of 90 m2.

Isla Urbana hopes to install over 1.2 million systems in Mexico City, which is approximately the number of households in Mexico City that have cisterns. Isla Urbana's systems are meant to be low cost. According to their estimates, if a family has a cistern and pump, the installation of a rainwater harvesting system, including labor, material and training is approximately 5,000 Mexican pesos. Thus, 1.2 million systems would cost approximately 6 billion pesos and potentially abate over 63 thousand metric tons of CO_2. In table 1, we compare the costs and abatement potential with projects listed in Mexico City's Climate Action Program. As we see in the table, RWH has a lower level of investment necessary to abate a ton CO_2 when compared to other initiatives Mexico City is considering.

Discussion

Due to increasing water demand and the realization that the overexploitation of the aquifer is unsustainable, Mexico City officials are considering expensive investments in additional water infrastructure projects. (Tortajada, 2000) Rainwater harvesting has the potential to supply Mexico City water users with a sustainable supply of water which could supplement its water needs. By relying on rainwater, Mexico City water users would have less need to rely on is overexploited aquifer. If rainwater harvesting were done at a large enough scale, it could make it unnecessary to invest in these politically unfavorable, expensive infrastructure projects. RWH has an advantage over large infrastructure projects in that it does not face the same political difficulties. For comparison, in 1997, officials initiated the Temescaltepec project to expand the Cutzamala sytem to increase the volume of water it delivers to the city. As of August 2012, the project still has not been initiated due to resistance by locals who fear that the project would dry up their water sources and affect their agricultural production. Rainwater harvesting does not face this same resistance. RWH systems can be installed on a case by case basis and whether the city wants 1 or 1 million systems is up to them and the funds that are available. With many in Mexico City currently suffering from poor water resources, a RWH can be used as a recourse for those who have no alternative but to put up with poor service or buy expensive PIPAS. RWH can also be used to help potentially ameliorate the dire condition that Mexico City's aquifer finds itself in by being a source of water for groundwater recharge projects. This should especially be considered in buildings with large roofs which can collect large volumes of water.

The NHBC study found that rainwater harvesting resulted in higher carbon emissions for buildings. This study hopefully provides a point of contrast with the NHBC study and emphasizes the point that when it comes to reducing emissions with RWH, context needs to be considered. Now more research is needed to see how RWH can be implemented on a larger scale throughout the Mexico City.

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