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# Beyond Just Light Bulbs: The Mitigation of Greenhouse Gas Emissions in the Housing Sector in Mexico City

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**Abstract.** Climate change is a serious global challenge that urgently demands comprehensive mitigation policies, including in the housing sector. However, GHG emissions assessment in the housing sector is particularly challenging because urban planning factors such as location of jobs and public transportation influence GHG emissions. Therefore, for mitigation strategies in the housing sector to be effective, they must be based on a comprehensive understanding of the complex nature of GHG emissions associated with housing development and use.

In Mexico, the Federal Government has implemented strategies for mitigating GHG emissions through the promotion of energy efficient technologies such as electricity-efficient light bulbs and solar water heaters. However, these strategies do not address GHG emissions stemming from the rapid growth of housing developments on the urban periphery. Recently, federal government-financed dwelling units have been developed on a massive scale in the urban fringe, without sufficient attention to public transportation and job creation.

In order to assess the impact of location and transportation on GHG emissions in the housing sector in the Metropolitan Area of Mexico City, a Life Cycle Assessment (LCA) was conducted to assess GHG emissions related to both construction and use of dwelling units. It was found that the use of gasoline for private transport is the principal contributor to GHG emissions, followed by the use of electricity and gas, respectively. These LCA findings suggest that the most effective mitigation strategy in the housing sector may be the promotion of resource-efficient dwelling units in urban locations. This calls into question the federal government's focus on technologies to mitigate GHG emissions instead of encouraging housing policies that support government financing of dwelling units on central locations that offer employment, services, and public transportation.

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**Introduction.** In housing units, residents use nearly 40% of the world's energy but also influence energy use in the transport sector (Pérez-Lombard, Ortiz, & Pout, 2008). Hence, a holistic assessment of the contribution of the housing sector is necessary to more effectively mitigate global GHG emissions. However, the vast majority of GHG assessments in the housing sector have been carried out in developed-world cities (Ramesh, Prakash, & Shukla, 2010). Thus, there is a poor understanding of the contribution to GHG emissions in developing-world cities, which are projected to embrace most global population growth in the following decades to come (Guerra, 2014; Stephan, Crawford, & de Myttenaere, 2012). By examining Mexico City, this investigation could enable a better understanding of appropriate climate change policies in the housing sector in the Global South.

Greenhouse gas (GHG) emissions assessment in the housing sector is particularly challenging because in addition to construction and daily use, urban planning factors such as density and location of jobs influence energy use and GHG emissions (Norman, Maclean, Asce, & Kennedy, 2006). It can be inferred from previous GHG assessments in the housing sector that urban density, which is largely influenced by the spatial location of housing developments, drives the extent to which residents use energy to commute from residential locations to job-rich areas (Fuller & Crawford, 2011; Hoornweg, Sugar, & Trejos Gomez, 2011; Lee & Lee, 2014; Stephan et al., 2012). Despite the fact that urban density significantly influences energy use, the vast majority of GHG emissions assessments in the housing sector disregard it (Ramesh et al., 2010). Stephan et al. argue that a more holistic approach to assess energy use of dwellings is indispensable to more effectively mitigate GHG emissions in the housing sector. The authors suggest widening the current typical scope of analysis, generally limited to household energy use, to also account for dwelling embodied energy, but more importantly to account for residents' transportation energy (Stephan et al., 2012). Household energy use includes cooling and heating of interior dwelling spaces, and the operation of domestic water heating and appliances. Energy embodied in dwellings includes the manufacture of building materials, transportation of building materials to the construction site, and construction processes. Residents' transport includes automotive transportation activities.

**A Life Cycle Assessment in Peripheral Housing Units in Mexico City: Investigative method.** Despite the fact that aggregate population growth rates in Mexico City decreased in recent years, population in the urban fringe has grown at an annualized rate of more than 10 percent from 1990 to 2010(Guerra, 2014). Even though rapid suburbanization of the Metropolitan Area of Mexico City, jobs remained fairly centralized within the limits of Mexico City (Guerra, 2014). This has led to increasing automobile use and an associated increase in GHG emissions, as residents in suburban housing developments commute to a select few districts in Mexico City that concentrate employment, educational institutions, and services. The study presented here examines the contribution to GHG emissions of the typical government-financed housing unit located in the urban periphery of Mexico City between 2000 and 2012. The characterization of the typical housing unit, which served to develop the LCA inventory, included three methods: a review of literature; two workshops with Mexican housing developers carried out between June and August 2011; and 17 separate field visits in peripheral housing developments in Mexico City, conducted between July 2011 and December 2011. It was found that government-financed housing units share various patterns in their mode of construction and in their urban fringe location.
Housing developments usually have only one entry point, to which access is typically restricted by a gate. In addition, housing developments are zoned as single residential land use areas, which means that commercial land uses are officially forbidden from being added over time. The

lack of non-residential uses means that residents are required to travel a considerable distance to meet basic needs such as buying food and other basic products, to access to any sort of public service, activity or amenity. The average distance to the closest subway station is 26.6 km, which helps explain why these housing developments are spatially disconnected from transit services, and why low-capacity buses and private cars are the main modes of transportation.

The LCA was carried out for the pre-use phase that includes building materials' manufacture, materials' transportation, and construction, as well as the use phase that includes household use and resident's transportation. A fifty-year service life was considered. This period is based on the most common approaches in LCA in buildings (Ramesh et al., 2010; Stephan et al., 2012), which enables comparison with previous LCAs. The housing unit (subject of the LCA) was considered to include the following systems: a) the dwelling unit as residential building, b) the adjoining public realm, including the components of the street such as sidewalks and pipelines, c) infrastructural elements, such as sewage treatment plants, and d) the household's resource consumption, including electricity, natural gas, water, gasoline, and diesel. See Figure 1. The environmental impacts of the elements related to the housing unit's life cycle were estimated for the functional unit: one square meter of habitable housing over a 50-year lifespan.

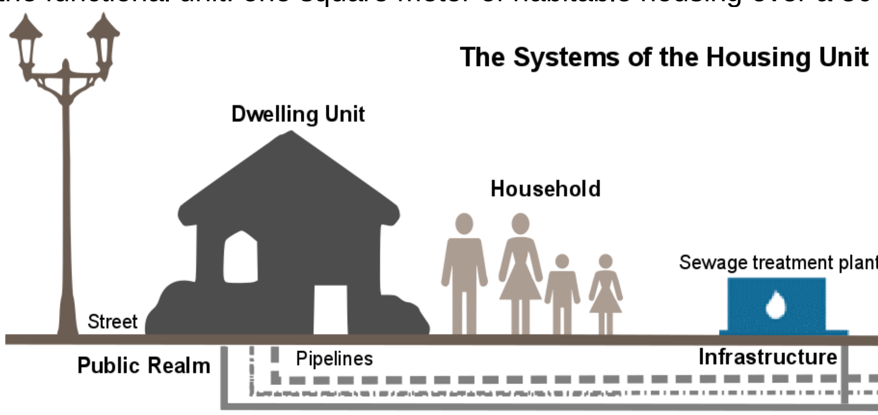


Figure 1. The Systems of the Housing Unit: dwelling unit, adjoining public realm, infrastructure, and household use

The open LCA 1.2.6 program was used to process the inventories of LCA. The environmental impact assessment method developed by the Center of Environmental Science of Leiden University (CML 2001) was selected to estimate global warming impacts as a function of estimated GHG emissions. The CML 2001 was regularly used in previous LCA assessments in the housing sector. This study included environmental impacts found in previous LCA studies of products elaborated and used in Mexico. For example, it included environmental impacts found in an LCA of the manufacture of asphalt in the Metropolitan Area of Mexico City. However, the main LCA reference database was the US-based National Renewable Energy Laboratory (NREL).

Two workshops with major Mexican developers were conducted in July 2011, in order to characterize urban and architectural patterns of the typical housing unit promoted by the federal government between 2000 and 2012. This architectural and urban characterization served to estimate flows of energy, building materials, and water for constructing the housing unit and its systems. Housing developers provided plans and databases that itemized earth-moving machinery to subdivide land and to build structures' foundations; the consumption of building materials, water, and energy to construct housing units' subsystems.

Flows of energy, water, and resources consumed during the household operating phase were determined from the results of a survey with 1,414 responses from households. The survey was conducted on 17 housing developments that collectively contain nearly 110,000 households. The sample is large enough to ensure a 99% level of confidence with a standard error of 3%. The mode of the survey was done by knocking on doors and asking residents a questionnaire in person. From field visits reports, it was estimated that nearly 50% of total dwelling units in these housing developments seemed to be vacant as housing units' conditions were dilapidated. Therefore, surveys were randomly conducted in dwelling units that were occupied by their residents. The total response rate was 70%.

The LCA inventory integrates flows of energy, resources, and materials required for the stages of pre-use, household use, and residents' transport. First, the manufacture of building components requires raw materials, energy, and water, which result in waste and GHG emissions. Second, transporting the components to the construction site requires the use of diesel, resulting in further GHG emissions. Third, the construction stage requires energy, water, and building materials, but generates GHG emissions and construction waste. Last, household use of the dwelling unit post-occupancy demands diesel, electricity, gas, gasoline, and water; these result in further GHG emissions and waste. It is worth mentioning that a sensitivity analysis was carried out to ensure the validity of LCA assumptions, and thus empirical data from surveys was compared with peer-reviewed articles and statistics developed by federal and local institutions[1].

**Results.** In order to estimate electricity flows, residents were asked how much they pay for their electricity bill and the frequency of this payment. After that, applicable electricity rates, measured in Mexican Pesos/kWh, were used to estimate flows of electricity (measured in units of kWh). It was estimated that the median value of annual electricity use accounts for 1,300 kWh, which was divided by dwelling construction area and then multiplied by 50 years of service life. Thus, electricity flows account for 1,625 kWh per square meter of habitable housing in a 50-year lifespan. In order to estimate flows of gas, residents were asked the type of gas they use (natural or Liquid Propane gas), how much they pay for their gas bill, and the frequency of this payment.

In order to estimate flows of gasoline and diesel, an origin-destiny survey was carried out. It included questions regarding the type and the number of means of transportation used to commute to job locations. These means of transportation include: walking, biking, bus, Bus Rapid Transit (BRT), subway, and private cars. Moreover, questions on the time spent in every means of transportation were included. After that, typical rates of gasoline and diesel usage per unit time were used to estimate flows of gasoline and diesel, in units of volume (NREL, 2012). Those rates were 2.25 liters of gasoline per hourly use of private car and 0.36 liters of diesel per hourly use of buses. Therefore, typical annual gasoline and diesel use accounts for 931 and 167 liters, respectively. In order to estimate flows of gasoline and diesel per square meter of habitable household in a fifty-year lifespan, gasoline and diesel consumption were divided by dwelling constructed area and then multiplied by household lifespan.

The origin-destiny survey helped identify four patterns of residents' transportation activities to commute to job locations. First, residents tend to use at least two means of transportation to commute to job locations. Residents spend an average of 143 minutes for daily commuting round trip. Second, buses seem to be the main transportation mode, in terms of time, since 53% of total commuting trips are done by bus. Therefore, residents use buses for 76 minutes per day.

[1] Researchers who are interested in the results of this analysis can directly contact the author.

However, most residents walk for several minutes before taking a bus. It was found that residents in peripheral housing developments are unable to access any high-capacity transit service, such as BRTs and subway. Third, residents use informal means of transportation to commute, such as second-hand vans and low-capacity buses. Fourth, 47% of total commuting trips are done using cars. This finding suggests that households living on the periphery remain less likely to drive. However, residents use private cars for 68 minutes per day. Peripheral housing developments are explicitly designed to encourage car ownership, since they provide room for parking in the front setback and because they have only one entry point (CONAVI, 2010). In order to reach some places, residents have to walk much further than the length of the most direct route that would exist if there were an interconnected street network.

Electricity use accounts for 30 kWh/m$^2$ per year, a relatively low value when compared to the average electricity use of dwelling units in the United States of 147 kWh/m$^2$ per year (Pérez-Lombard et al., 2008). It is worth emphasizing that Mexico City's weather is fairly temperate throughout the year, and thus the use of HVAC systems for heating or cooling interior spaces is negligible (UNEP, 2009). Electricity use attributable to HVAC systems is significant in places that have extremely cold or hot temperatures in winter or summer, respectively (Ramesh et al., 2010); however, this is not the case of Mexico City. Therefore, it can be concluded that electricity use is mainly related to the operation of lighting and appliances, such as light bulbs and refrigerators. Hence, it can be argued that the most significant GHG mitigation outcomes can be achieved by promoting energy efficiency in residents' transportation-related energy usage rather than household-related energy consumption. Table 1 shows main results of the LCA inventory.

Table 1. LCA inventory: flows of energy, materials, and resources per square meter of habitable household in a fifty-year lifespan

| Input | Stage | LCA Phase | Flow |
|---|---|---|---|
| Concrete | Dwelling embodied | Pre-use | 980 kg |
| Steel | Dwelling embodied | Pre-use | 18 kg |
| Asphalt | Dwelling embodied | Pre-use | 6 kg |
| PVC | Dwelling embodied | Pre-use | 5kg |
| Water | Dwelling embodied | Pre-use | 79 liters |
| Water | Household operating | Use | 413 m$^3$ |
| Gas | Household operating | Use | 430 liters |
| Electricity | Household operating | Use | 1625 kWh |
| Gasoline | Residents' Transport | Use | 931 liters |
| Diesel | Residents' Transport | Use | 167 liters |

LCA revealed that the total contribution of the housing unit to GHG emissions accounts for 3,750 kg $CO_2$ equivalent per square meter of habitable household in a 50-year lifespan. It was found that 92% of total GHG emissions occurs during the use phase that aggregates household use and residents' transport. Dwelling embodied energy[2], contributes 8% household-operating stage 42%, and residents' transport 50% of total GHG emissions. The LCA revealed that the use of gasoline and diesel that result from residents' transport is the principal contributor to GHG emissions with 50%, followed by the use of electricity with 22% and gas with 20%.

[2] The manufacture of concrete is the main contributor to GHG emissions of dwelling embodied energy, and it contributes to 7% of total GHG emissions.

**Conclusion.** LCA exposed that residents' transportation is the main contributor to GHG emissions in suburban housing developments promoted by the Mexican federal government between 2000 and 2012. In addition, LCA revealed that electricity use is the second most important contributor to GHG emissions. LCA findings elucidated the disconnection between housing policies, which largely promoted new housing developments in the urban fringe and climate change policies in the housing sector, which have a primary focus on promoting energy-efficient technologies in peripheral housing developments. It is apparent that these GHG emissions mitigation policies in the housing sector effectively disregarded urban density, which is the leading factor determining the extent to which residents use energy to commute to their jobs (Fuller & Crawford, 2011; Lee & Lee, 2014; Stephan et al., 2012). The problem is not the promotion of energy-efficient technologies so much as making them the federal government's sole climate policy focus; i.e. the failure has been to rely on energy-efficient technologies to mitigate GHG emissions in housing developments placed on the urban periphery while effectively ignoring the resulting increases in car usage and accompanying GHG emissions.

One possible avenue for GHG emissions mitigation in the housing sector that comprehensively integrates housing policies and technological innovations may be affordable housing densification in central areas. Despite assumptions that Mexico City is already densely developed, scholars argue that numerous vacant lots and underutilized buildings in central locations offer opportunities for urban densification (UN-HABITAT, 2011; Ward et al., 2014) While federal housing policies continue to facilitate government-financed housing developments on the urban periphery, privately financed high-rise residential building development is increasingly occurring in central locations (Eibenschutz Hartman & Benlliure B., 2009). Unfortunately, while such redevelopment of central locations may contribute significantly to GHG mitigation, these high-rise developments are priced out of reach for low-income people. Since wealthier people have smaller households but utilize more space, the result of this gentrification process may be a decline in the number of lower-income residents in some areas of the central city. In addition, rehab housing strategies with energy-efficient technologies in central locations may be another effective GHG emission mitigation strategy in the housing sector (Ward et al., 2014). Energy-efficient technologies, such as solar water heaters and solar panels, could significantly reduce energy use and attendant GHG emissions without inducing car usage.

Beyond the case of Mexico City, this investigation suggests that LCA represents a powerful methodological approach to develop comprehensive GHG emission baselines for the housing sector, which in turn can serve to encourage effective housing policies for mitigating GHG emissions in the housing sector. A comprehensive GHG emissions baseline in the housing sector is essential to design, evaluate and verify GHG mitigation strategies in the housing sector over time. Mexico City could enable a better understanding of appropriate climate change policymaking in the housing sector that could serve as reference to other developing-world cities in the Global South.

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