Towards a Low-Carbon Urban Housing Sector in Colombia

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Abstract

Low-carbon concepts in the construction industry have been one of the most widely discussed topics among researchers interested in studying sustainability issues within the built environment. Over the last years, many investigations have been focused on examining greenhouse gas (GHG) emissions produced by the housing sector. This paper presents the preliminary findings of an on-going study, which is directed towards generating an abatement cost curve of GHG emissions for urban residential buildings in Colombia and formulating alternative scenarios for public policies, up to 2040. Three major Colombian cities (i.e. Bogotá, Medellín, and Barranquilla) were studied through the characterization of their housing stock and a multivariable forecast of the CO2-eq emissions generated during the building life cycle of their typical residential projects. Characterization was based on a literature review and statistical data analysis. Emissions were estimated by taking into account the different life cycle phases for representative residential projects in each of the urban areas under analysis, current building technologies and energy consumption patterns. This was carried out by conducting interviews with main actors of the Colombian construction industry, using information from real projects, and employing energy-efficiency simulation software along with the national energy balance data of the National Planning Unit of Mining and Energy (UPME in Spanish). Preliminary results show that many Colombian households live under low comfort and health standards. Therefore, conclusions seek to highlight not only the importance of reducing GHG emissions; but also, the relevance of improving the living conditions of the Colombian households. The study was financed by the British Embassy in Colombia and developed under the supervision of the Colombian Green Building Council (CCCS in Spanish); results are part of the National Low-Carbon Development Strategy (ECDBC in Spanish), in process of formulation by the Colombian Ministry of Environmental and Sustainable Development.

Keywords: Sustainable building, Greenhouse Gases Emissions (GHG).

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1. Methodology

Building Life Cycle Analysis (LCA) was the base methodology of the study and was applied through the process of calculating GHG emissions, evaluating the mitigation potential and estimating the associated costs. According to this, every life cycle phase: materials extraction and the transformation and transportation to the construction site, design phase, actual construction of the building, use and operation phase, and finally the decommissioning, demolition and final waste disposal, should be analyzed in order to identify GHG reduction opportunities.

Three Colombian cities, Bogotá, Medellín and Barranquilla, were selected to carry out the analysis due to their representativeness in terms of climate and socio-economic conditions around the entire country. According to the building categories defined by the Colombian Department of National Statistics (DANE in Spanish) (2011), there are two (2) residential segments, low income residential units (VIS in Spanish), and other than low income residential Buildings (No VIS in Spanish), two (2) typologies, houses and apartments, and three (3) construction methodologies, that represent the major portion of the buildings around the country including: confined masonry, structural masonry and reinforced concrete high rise buildings, all combined conform a group of 12 categories. "Real" case projects were studied, for every category which were significant and whose information was available and appropriate for purposes of this investigation. Therefore 12 building prototypes were defined per city, for a total of 36 prototypes at a national level. These 12 categories represented the entire building stock of Colombia. Using information provided by DANE, the total residential units were distributed within the defined categories.

During the first stage of the investigation, the research group developed a characterization report of the building sector in Colombia including a historical brief about the housing industry in Colombia, growing rates, and how the building activity has coped with the increasing urban housing deficit of the country, calculated in 2.2 million units until 2011. In order to describe the complete residential building stock, important milestones, the most influential policies and regulation were mentioned as well. It also included a description of representative construction techniques and a quality analysis of houses and apartments.

The information required for every project included: architectonic and technical designs, list and specifications of building materials, cost estimates of the building, and energy consumption during construction. The emissions at the first year, for the operation phase specifically, were calculated for the entire stock per city by defining the consumption behavior. In order to characterize households' energy consumptions, the study also took into consideration information from different studies performed by the UPME and from the Unified System of Public Utilities Information (SUI in Spanish). GHG counting for materials were calculated using the methodology of the Intergovernmental Panel on climate change (IPCC) and local studies to consider specific local characteristics of the sector in Colombia.

The methodology is also aligned with the Energy Assessment Protocol of the US Environmental Protection Agency (EPA) and the Common Carbon Metric document developed by UNEP Sustainable buildings & Climate Initiative. A National GHG emission inventory developed by the National Institute of Hydrology, Meteorology and Environmental studies (IDEAM in Spanish) was also used as a reference.

The GHG emissions baseline at a national level was intended to be determined for every project life cycle phases, and at least two scenarios were considered: an inertial scenario or Business as Usual (BAU), and a reference scenario that incorporated new technological, political or socio-economic conditions.

At the construction stage, GHG emissions baseline was calculated for two different aspects. First, the GHG emissions of producing and transporting the amount of cement, clay bricks, steel and glass result of buildings quantity's take-off. No other materials were considered because they do not have enough information for calculation a local GHG emission factor. Second, the energy consumed at the construction site (heavy machinery, other construction and administration equipment). GHG emissions due to construction waste were not considered because the information available was very limited.

LEAP (Long Range Energy Alternatives Planning System) software allowed the evaluation of energy policy and climate change mitigation actions during the activities of energy production, transformation and consumption. The GHG emissions allocation considered two residential segments low-income and other than low-income residential units, and the three cities under evaluation. That way, two average households were defined per city for a total of six consumption prototypes. There was no difference in terms of materials or construction technique, from the consumption point of view.

The growth rate of the residential units at every city and the Inertial (BAU) were calculated. The reference scenario was calculated; incorporating the mitigation goals included in the Rational Energy Use Program (PROURE in Spanish), and considered that the income per capita is increasing the energy intensity of residential units. GHG emissions baselines for the decommissioning and demolition phase were not calculated due to incomplete information.

Regarding mitigation actions, three building life cycle phases were considered including: design, materials production, construction and operation phase. Relevant mitigation actions were reviewed in a literature review (i.e. International Code Council, 2010), and were classified into applicable and non-applicable, according to the national context of the building industry. The list of applicable measures was validated in one of the focus group meetings carried out as part of the ECDBC.

In order to evaluate actions applicable at the design phase, a bioclimatic simulation was performed in each of the 36 prototypes using the software HEED (Home Energy Efficient Design). This software supported analysis of all different design alternatives such as architecture, ventilation, lighting, materials, etc. The simulation aimed for improving comfort conditions and reducing energy consumption. Other aspects that are also considered in the simulation included electronic and gas equipments that registered the highest consumption in every residential segment, reported by the Unified System of Information, SUI (2012). The mitigation actions evaluated included measures applicable for new and existing residential units, where “Retrofitting” processes were considered. The final results of the simulation provided a reduced amount of GHG emissions and the annual costs for energy consumption.

At the construction phase, mitigation actions during the production phase of the most important materials were evaluated. A determined pace of adaptation, to new and better technologies, was taken into consideration.

Regarding mitigation actions at the operation stage, the alternatives considered included actions towards lighting and refrigeration efficiency, fuel substitution and implementation of new fuel sources and technologies. The applicability of these actions was evaluated based on their positive effect in terms of energy efficiency and the possibility of using existing mechanisms for its implementation. Variations of energy consumption patterns and implementation of non-existing standards or regulation were not taken into consideration. A new reference scenario was defined to address the issue that most of the houses in Colombia are below minimum comfort standards, in terms of temperature, and that per capita income could increase significantly, therefore many households will start making use of more HVAC (Heating, ventilation and air conditioning) equipment in order to achieve a higher level of comfort.

Finally, based on the estimation of the GHG mitigation potential of the actions defined for every buildings life cycle phase, and their associated costs, the abatement cost curves were calculated.

2. Scope Adjustment

According to the characteristics of the information available, the investigation had many limitations. The scope of the project at every life cycle had to be redefined, as it follows:

2.1 Materials Production Phase

A complete estimation of GHG emissions due to materials should considered the entire processes, beginning at the extraction of raw materials, transport to the plant, the transformation process, the disposal of waste material and finally transport to the construction site. Due to the lack of information about the mining (raw materials extraction), and transportation activities in Colombia, the scope at this stage was limited to GHG emissions for fuel consumption and direct emissions at materials production plants.

Regarding mitigation actions during the production of materials, it was possible to analyze actions, at an acceptable level of detail, applicable just to the cement industry. Other materials industries did not provide appropriate information.

2.2 Construction Phase

The construction phase was defined as the sequence of processes at the construction site. The GHG emissions baseline was calculated including energy consumption at the construction site and transportation of cement from the plant to the construction site.

GHG emissions calculation at the construction phase can be only used as a reference, because only three projects out of the 36 analyzed had precise information about their fuel, electricity and other energy form consumption. Therefore, GHG emissions mitigation actions were not evaluated.

2.3 Use and Operation Phase

At the operation phase, different energy uses were considered. As mentioned before, the information included studies from UPME, DANE, SUI, that information allowed the characterization of household energy consumption including: consumption behavior, equipments; for different geographic regions and socio-economic conditions. That information allowed the calculation of a GHG emissions baseline. Energy consumption figures for the residential sector are updated permanently. Information is adjusted very frequently, affecting the mitigation potential of the actions considered and their associated costs.

The reference scenarios, considered at the operation phase, included replacement for more efficient equipments at a certain scale, consumption pattern modifications, higher levels of comfort, and fuel / energy substitution. The software used to estimate the impact of the mitigation actions was LEAP.

2.4 Design Phase

In order to evaluate the impact of mitigation actions related to technical and architectonic design, the study used the results of bio climatic simulation in HEED. It was assumed that every prototype has HVAC equipment, so every action was evaluated based on its capability of producing a positive impact in comfort and energy efficiency. For baseline calculation purposes, it was considered that residential units will have an acceptable level of comfort that means higher energy consumption (according to the criteria defined by IDEAM).

Mitigation actions included: building orientation, residential unit lay-out, interior and exterior walls isolation, solar protection elements, inner temperature, lighting and humidity control, interior finishes, natural ventilation, etc. Actions were categorized into three packages: Package 1 - passive actions in new designs, Package 2 - active actions in new designs, Package 3 - retrofitting that applies to new designs and existing buildings, some of these actions were taken from S.E. Chidiac, E.J.C. Catania, et al (2010). These packages of actions were implemented in four scenarios as seen in Table 1.

Table 1: Scenarios for mitigation actions implemented at the design phase

Scenarios	Description	Period of application	Other assumptions	Residential units implementing the measure
Short term - applies only for new projects.	A new green building code is implemented and will require Package 1 actions	2013-2018	Implemented at all new projects.	512,881
Midterm - applies only for new projects.	The construction industry embraces Package 2 actions.	2019-2024	Implemented at all new projects.	736,927
Long term - applies only for new projects.	The construction industry apply Package 3 actions.	2025-2040	Implemented only in the other than low income projects.	328,042
Midterm – applies for existing projects	Properties apply Package 3 actions.	2019-2040	Implemented for 20% of the low-income segment units and 50% of the others	10,956,865

2.5 Demolition and Decommissioning Phase

Information regarding required energy resources at demolition activities, transport and disposal of demolition waste, and recycling opportunities was unavailable or incomplete, so this phase was completely excluded from the study.

2.6 GHG Emissions forecast

In terms of building sector growing forecasts, two scenarios were defined: an inertial (BAU), where housing deficit was calculated based on the families conformation and the historic rates of residential units production, and a reference scenario that took into consideration the governmental goals of reducing housing deficit, established in the document Vision 2019, by promoting residential large scale projects. These scenarios are presented in Figure 1 for the use and operation phase.

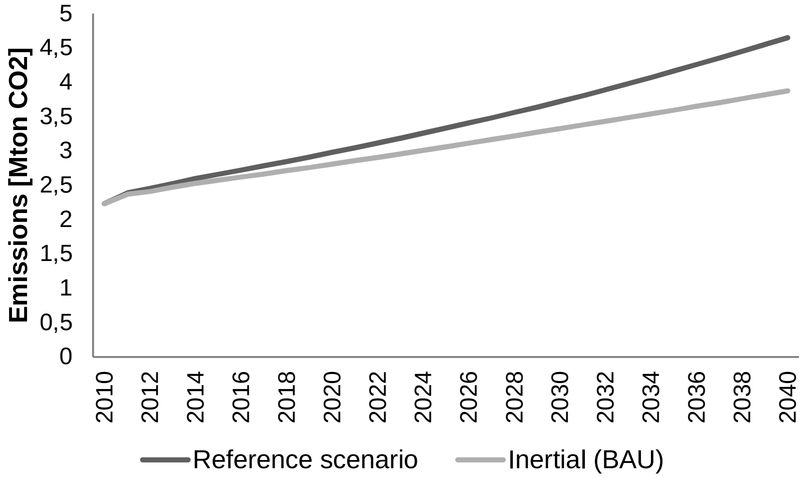

Figure 1: Inertial and reference scenarios in the use and operation phase.

Due to the limited information about the building sector explained in detail later on the article, the initial scope had many modifications, as seen in Table 2.

Table 2: Project Compliance

Activity (as defined in the initial scope)	Description	Materials Production phase	Construction phase	Use and Operation phase	Design phase	Demolition phase
1	Available data collection	Included	Included	Included	Included	Included
2	Building sector characterization	Included	Included	Included	Included	Not Included
3	Building sector Forecast	Included	Included	Included	Included	Not Included
4	Identification of available actions	Included	Included	Included	Included	Not Included
5	Abatement cost curve	Included	Not Included	Included	Included	Not Included
6	Cost / benefit analysis	Included	Not Included	Included	Included	Not Included
7	Co-benefit analysis	Included	Included	Included	Included	Not Included

3. Unavailable data and assumptions

3.1 Building Stock Composition

In Colombia, a very critical housing phenomenon is what it is called “informality” which consists on an accelerated growth of the residential stock most of the time driven by the “self-construction” sector. These residential units, generally at the low- income segment, are built with no licenses or permits, sometimes with low-quality materials and at high geological risks areas. There are very few studies about “informality” in Colombia. They indicate that the dimension of this sector ranges from 40% to 50% of the entire building stock and provided description of the technical conditions of the houses. The predominant construction technique for this segment is masonry at a maximum of three storey buildings. That information was useful to include this important category in the estimation of the stock. However, it is important to mention that the results presented at this study can be highly affected by any new consideration about this issue.

3.2 Forecast

There is not official Information about population growth through 2040, for every region included in the study. It was assumed that the population increase rate estimated for 2008-2020 will be the same for the period between 2020 and 2040. However, it is not expected that the three cities analyzed follow the same dynamic throughout the period under study.

Similarly, there is not official information about the households’ size by 2040, so it was assumed it will remain constant during the period under study. It has been observed that families are reducing their size, so the residential units demand could be underestimated at the long run. Finally, governmental goals in terms of reducing deficit are not very clear in any of the cities analyzed.

3.3 Materials Production Phase

There is no detailed published information regarding GHG emissions of construction materials produced in Colombia, specifically, information about current production techniques and technologies, the type and amount of energy consumed in the processes, the specifications of mining equipment to extract raw materials, fuel consumption for all different transport, vehicle types, number of trips and distances, is very limited. In general, materials producers don't have current documents about the impact of GHG emission mitigation actions.

3.4 Construction Phase

Only three projects out of the 36 analyzed documented information of their energy consumption during construction. No specific activities were identified for the energy used reported. That limited the identification of GHG emission mitigation actions. It would be necessary to have a complete characterization of the heavy machinery available in Colombia in terms of technologies and energy used.

One of the construction techniques, identified by DANE as the most representative in Colombia, is the "industrialized systems". Its definition, for the building census purposes, was very imprecise; therefore, in this category were classified a very important number of buildings. For some cities industrialized means "manufactured houses", but in other regions the category was used for high rise buildings with reinforced concrete structure.

There are no records of previous large-scale studies evaluating GHG mitigation actions at construction sites. Another important difficulty was finding official information on energy consumptions due to the residential building activity. UPME reports consumption for the construction activity in general, making no difference between buildings and infrastructure.

3.5 Use and Operation Phase

At the national energetic records, there is no differentiation between household consumption per city, or region and use, so the variations of consumption patterns, due to climatic and cultural conditions, are difficult to determine. Similarly, the type of electronic equipment at the different segments of residential houses has not been fully characterized.

It would be very helpful having official current sales statistics on electric and gas equipment at every region. That would provide an indication of the increasing acquisition of equipments to improve comfort inside the residential units due to an observed increasing per capita income. Regarding the evaluation of the GHG emissions actions at the operation phase, it was very difficult to estimate the maintenance local costs associated with the implementation of the different actions, and provide a complete cost / benefit analysis.

By the end of this study, there is no an officially published study regarding energy consumption of the urban and rural residential sector, so it was not possible to use it for purposes of this study. The information that will be provided at this study will address many of the difficulties mentioned before.

3.6 Design Phase

There were compatibility issues between the climate information available and the bioclimatic simulation software. Also, It would be very useful if we had a unified local materials data base compatible with the simulation tools. The information provided by developers of some of the prototypes was incomplete in terms of their technical specifications.

The local definition of comfort or better quality conditions could be evaluated. It is necessary to propose local criteria that incorporate cultural, physiological, social and other contextualized relevant aspects that can be included in the local regulation.

3.7 Demolition and Decommissioning Phase

For this particular phase, we observed lack of information of most of the relevant issues including:

1. Buildings life span
2. Characterization of demolition or retrofit waste
3. Rates of demolition activities in the cities
4. Recycling potential and required resources
5. Amount and quality of construction waste arriving at disposal sites.

4. Conclusions

This study was the first evaluation of GHG emissions of the residential sector at a national level. According to international defined protocols, an inventory of GHG should be divided by those sectors that produce the emissions. However, emissions from the residential sector, as seen in this study, considered all building life cycle phases. The residential sector has emissions that can be allocated to industry (materials), energy transformation and distribution, waste management and transportation sector; therefore it is a transversal or crossover sector. Consequently, the results may contribute to other sectors´ figures. Seen as an end user sector, it would only contribute with the emissions associated to activities at construction sites. Through this study, we identify the importance of having studies to determine all interactions between sectors and its implications in policy and mitigation actions that can be implemented by users.

This study incorporated the preliminary results of other sectors participating in the ECDBC. This collaboration provided better insight in terms of collateral benefits and external issues of the mitigation actions identified. Through the study it was observed that there is an important necessity of evaluating different models of city and regions, and their impacts on GHG emissions together with other relevant indicators. Territory planning and configuration should incorporate GHG considerations that could have collateral environmental, economic and social benefits or requirements.

Through bioclimatic simulations, it was concluded that most of the population lives in uncomfortable conditions even at new residential developments. Temperatures early in the morning in cities such as Bogota are much lower than the comfort threshold defined by IDEAM. In cities such as Barranquilla, that have very warm weather, the comfort rate was only 10%. It was observed that the population presents a low-consumption attitude. However, it is uncertain what would happen if the country keeps on a sustained economic growing pace. It was confirmed, through this study, that Colombia has a very low emission level, 0,37% of the world’s total GHG emissions. However, it was observed that doing nothing would lead us to an emission level much higher than we expect. It can be said that better social and economic conditions will necessarily represent higher household's energy consumption, so the actions proposed in this study may have a critical impact.

Having said that we have a low emission level, it is also important to mention that the emission index in terms of the Colombian GDP is very high, 0.7 Kg Co2-eq / PIB per capita in PPP (Purchasing Power Parity). Therefore, mitigation actions towards to materials production sectors and construction sites could have a positive impact in their productivity and profitability margins of those sectors. In general, actions that address energy efficiency could lead organizations to document, improve and control many processes, having a positive impact on health and safety procedures.

Mitigation actions considered at the operation stage are basically related to energy efficiency. Traditional measures such as solar water heating were included. The application of these actions may depend significantly on developers, who can have a better insight of the financial implications through the results provided in this study.

In Colombia emissions due to materials are more significant, compared to cases registered in international literature. It was concluded that the contribution of emissions at the operation stage is low. A low comfort level is one of the causes.

It was concluded that emissions increase at a low rate, because our energy is mostly produced at hydroelectric projects. However, and as said before, emissions may increase unexpectedly due to higher GDP per capita. The mitigation actions proposed could balance higher consumption. However, from 2030 it is observed that we will need to implement alternative technologies and more ambitious GHG goals to maintain our emissions at an inertial level, which can be a good scenario for international trade and negotiations.

The evaluation of mitigation actions related to technical and architectonic design show that implementing basic bioclimatic design principles have a positive impact in comfort and GHG emissions, at a very low cost. These kinds of actions, that have more improved technical requirements, have collateral benefits in terms of economic development and competitiveness of the building sector.

There is a package of design actions that have important benefits in terms of comfort and GHG Emissions at a high implementation cost. Those actors administrating buildings and other residential assets will perceive the financial benefits of these measures. This suggests that residential development schemes such as DBO (design, build and operate) have better financial performance through the implementation of GHG mitigation actions. These mechanisms would not only contribute to the quality of residential products and energy efficiency features, but also may have a positive impact on the housing deficit.

The lack of information related to the residential sector, and identified through this study, will facilitate the formulation of future studies and research projects. For example, comprehensive characterization of the informality phenomenon in Colombia would allow the government to address many issues associated with this enormous problem, including critical social aspects.

One of the most important conclusions of this study is to confirm that the relative importance of the new houses over the entire stock is very low. So, the priority may be intervening houses at the operation phase. This confirms the importance of promoting renovation and improvements to houses.

5. Recommendations

1. It is recommended to carry out studies with wider environmental criteria. Air quality, comfort, health, and impact on water bodies are very critical issues in Colombia.

2. Incorporating urban planning topics to the discussion of GHG and other environmental issues may provide more integral solutions.

3. The informality phenomenon should not be addressed with an "elimination" approach, and it must be found a systematic and strategic mechanism of transformation and improvement of the significant portion of the building stock under this category.

4. It is necessary to establish housing observatories that provide information on the dynamics of the building stock.

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