Net-zero energy housing virtual Article 6 pilot

Net-zero energy buildings in Cartagena, Colombia

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Summary

Article 6 of the Paris Agreement provides the framework for a new generation of carbon markets in a context where all countries are supposed to formulate and implement ambitious Nationally Determined Contributions (NDC) towards a temperature target and ratchet their contribution on a regular basis. Under this new regime, carbon market mitigation activities must account for, encourage and enable – and most importantly not be a disincentive for increased domestic climate action. With the final rules for Article 6 being an issue of ongoing negotiation, virtual pilots can help contribute to the discussion regarding rulemaking for Article 6 and inform new approaches to cooperation. NewClimate Institute identified the construction of net-zero energy buildings (NZEBs) in Colombia as a promising emission reduction option for a virtual Article 6 pilot.

Buildings represent a fifth of the total energy use in Colombia and specifically residential buildings emitted about 4.4% of the country's 2014 total emissions, excluding the agriculture, land-use and forestry sectors. Emissions from the sector are expected to increase by 3.3% per year in the next two decades, reaching 17 $MtCO_2e$ in 2040. The sector is included in the Colombian NDC and is expected to contribute to the overall target of a 20% reduction in economy wide greenhouse gas (GHG) emissions by 2030 compared to the business as usual (BAU) scenario.

There are various plans for incremental energy efficiency improvements in Colombian building codes, but implementation has been a challenging process and there is no plan for a medium to long-term decarbonisation of the sector. Drawing on previous research on the building sector in Colombia and emerging efforts to promote sustainable construction in other countries, we investigate the potential of an Article 6 supported initiative to promote NZEB construction for residential buildings.

Introducing NZEBs to Colombia has the potential to improve construction practices, reduce energy consumption, realise monetary savings both for residents and the Colombian government, increase energy access and security, improve personal health and comfort, as well as reduce emissions. For our virtual pilot study, we take the Puerto Madero housing project as a case study. Puerto Madero is a planned development of 448 housing units built to Passive House standard in Cartagena. Baseline determination is extremely challenging, depends on a large number of factors, and would require further sampling and assumptions. Further we found that baseline determination is likely associated with high transaction costs and other barriers such as willingness of residents to share information on their energy use. Our case study however provides a rough bottom up estimate of what costs and emission reductions could be. We find that a building of 48 housing units similar to those in the Puerto Madero real estate development that is upgraded to net-zero energy basis could reduce emissions by approximately 58 tCO_2 per year, compared to standard newly built houses.

Encouraging NZEB construction has the potential to support the transformation of the Colombian building sector. While policy developments in the Colombian building sector are moving in the right direction and aim to improve energy efficiency, examples of net-zero energy concepts are missing. We found no existing or planned NZEB projects in Colombia and only a few examples of NZEBs in tropical, humid regions in other parts of the world. If realised, an NZEB pilot would seek to leverage experience from other parts of the world where NZEBs have been developed for the social housing sector in order to build capacity among architects, construction companies, finance institutions, and housing buyers in Colombia. Though based on only one example, our case study cost assessments indicate that an NZEB comes at approximately a 15% price premium compared to standard buildings. The financial attractiveness of the suite of measures to bring about NZEBs for housing buyers is heavily dependent on their income level and the socio-economic grouping that determines their eligibility for electricity subsidies. Regardless of income level and socio-economic grouping, the price premium of an NZEB comes at a significant financial risk with regard to the upfront investment. If NZEBs become more common, however, supply chains would develop, economies of scale could be found and costs are

expected to decrease. Depending on the business model chosen, an Article 6 based pilot would encounter various challenges on an individual project basis, notably in terms of costs for robust baseline assessment but would likely make more sense if implemented on a (sub) sectoral level rather than a collection of individual one-off projects. If developed further, such a pilot should only last for a limited time to support ambitious early adopters. Indeed, subsidies that households receive from the government for electricity and gas are a financial disincentive to invest in efficiency and could be considered in a larger reform package.

An Article 6 pilot would very likely be both additional and otherwise inaccessible in Colombia without foreign support. First, as explained, NZEBs are uncommon to non-existent in Colombia and (more widely) Latin America. Second, the various components of an NZEB are underdeveloped in Colombia: Domestic regulations do not currently push the market towards more optimised building design and practices, nor efficient appliances; the Colombian residential solar PV market is immature compared to other Latin American countries; and notably there is no significant existing distributors for mechanical ventilation with dehumidification systems in the local residential market context. These constitute a barrier to the large-scale uptake of NZEBs.

Three possible business models for the development of NZEBs in Colombia include an Energy Service Company (ESCO) business model, a bank subsidised interest model, or a real estate developer focussed business model. In the ESCO business model, a housing construction company would build NZEBs and sell them at prices close to the price of standard buildings. Residents would pay close to the standard price of housing, with the difference between a standard building and an NZEB being paid for by an Energy Service Company (ESCO). Instead of having zero energy costs, as they would have had they paid for the NZEB outright, residents would pay the ESCO a monthly energy service fee that is slightly reduced from the price that they would have paid for electricity and gas in a standard house. Such an energy service fee, combined with the sale of ITMOs could provide the ESCO with a revenue stream that could be used to recoup the initial price premium over the price of a standard residential building over a number of years. In the bank subsidised interest model, a local financial institution could use the sale of ITMOs to subsidise interest rates for mortgages of energy efficient housing units. House buyers would pay the full price of an NZEB building but would have no energy costs thereafter. The level of subsidy would be dependent on what is necessary to increase the NPV of the investment to the housing resident and would depend on the energy prices that the resident would have paid, which are tied to their socio-economic grouping. In the third real estate developer business model, a developer could build and sell NZEBs for a standard price competitive with other residential housing. The cost difference could be covered through the sale of ITMOs. Such a model would however imply relatively high per tonne prices. Potential price impacts from a share of proceeds for adaptation and for an overall mitigation of GHG are not taken into account here but should be implemented along the lines for Article 6.

Based on our assessment that the pilot project is both additional and inaccessible, Colombia would likely not be endangering its own NDC achievement if it were to approve the pilot project, export mitigation outcomes, and apply a corresponding adjustment. To do so, however Colombia would require additional institutional capacity and resources to conduct annual GHG inventories. The national registry of emission reductions (RENARE) could be well adapted to track Article 6 transfers. The mandate of the DNA would further require a specific change to carry out corresponding adjustments with important implications for NDC achievement. In order to maximise the transformation potential of the housing sector in Colombia however, any Article 6 measure should ideally be complemented by a number of policy measures including a reform of the electricity pricing system for various socio-economic groups, minimum energy performance standards for appliances, and the improvement of implementation and enforcement of building codes. International technical assistance would play an important role in this respect.

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Abbreviations

A/C	Air Conditioning
BAT	Best available technology
BAU	Business as usual
BUR	Biennial Update Report
CDM	Clean Development Mechanism
CFL	Compact Fluorescent Lamps
CMA	Conference of Parties serving as the meeting of Parties to the Paris Agreement
CONPES	National Council of Economic and Social Policy (*El Consejo Nacional de Política Económica y Social*)
COP24	Conference of Parties 24 in Katowice
DNA	Designated national authority
DOAS	Dedicated outdoor air system
EE	Energy Efficiency
EIA	Environmental Impact Assessment
GHG	Greenhouse gas
HFC	Hydrofluorocarbon
ITMO	Internationally transferred mitigation outcomes
kW	Kilowatt
kWh	Kilowatt hour
LED	Light-emitting diode
LPG	Liquefied petroleum gas
LULUCF	Land use, land-use change and forestry
MEPS	Minimum Energy Performance Standards
NAMA	Nationally Appropriate Mitigation Actions
NDC	Nationally determined contributions
NPV	Net Present Value
NZEB	Net-Zero Energy Buildings
OMGE	Overall mitigation of global emissions
PAS	Sectoral Mitigation Action Plans
PV	Photovoltaic
RENARE	Colombian national registry of emission reductions
SDGs	Sustainable Development Goals
tCO2e	Ton of carbon dioxide equivalent
UNFCCC	United Nations Framework Convention on Climate Change
UPME	Mineral / Energy Planning Unit (*Unidad de Planeación Minero-Energética*)

1 Introduction

Article 6 of the Paris Agreement provides for a new generation of carbon markets. There are a number of fundamental changes between the Paris Agreement and the erstwhile Kyoto Protocol, notably the universality of Nationally Determined Contributions, the ambition ratchet mechanism, a balance of emissions and sinks by the second half of the century, and the agreed overall temperature target. These differences call for a new approach to market mechanisms. Importantly, mitigation activities must account for, encourage, enable, and, most importantly, not be a disincentive for increased domestic climate action.

The flexibility mechanisms of the Kyoto Protocol evolved over time and policy makers learned about markets as a policy tool through piloting and engaging with them. In a similar manner, virtual pilots can help contribute to the discussion regarding rulemaking for Article 6 of the Paris Agreement. Thinking through emission reduction pilot activities based on real-world contexts can help inform new approaches to cooperation through carbon markets. NewClimate Institute has identified the construction of net-zero energy buildings (NZEBs) in Colombia as a potential emission reduction option for an Article 6 pilot. A net-zero energy building minimises energy demand and produces enough renewable energy onsite to offset energy consumed from the grid. The net-zero status is achieved through optimising the building design, installation of efficient appliances, replacing natural gas-based cooking with electric stovetops and installation of on-site solar PV. The pilot could potentially serve as a role model that supports decarbonisation in new houses and fosters ambition raising in the Colombian building sector.

We understand a "virtual Article 6 pilot" to be a thought-exercise that explores the framework and scope of an activity, and that provides the necessary information to move the investigation towards actual piloting of the proposed mitigation activity. Important elements when considering a pilot for the future of Article 6 include additionality, baseline setting, inaccessibility, and promoting and enabling increased climate ambition through a focus on technologies that further sectoral change and enable more host country NDC ambition in the future. Further aspects include compatibility with and contribution to decarbonization around mid-century, congruency with host country priorities, and a contribution towards the achievement of Sustainable Development Goals.

2 Background and Context

2.1 Current situation

Colombia's first Nationally Determined Contribution (NDC) sets a target of 20% reduction in economy wide greenhouse gas (GHG) emissions by 2030 compared to the business as usual (BAU) scenario. This reduction target can be increased to 30% if international support is provided (MinAmbiente, 2015). The national target is to be passed down equally among the following sectors: energy, housing, industry, transport, agriculture, and forestry. In other words, the government expects each sector to reduce its emissions by 20% by 2030 below the sectoral BAU (IDEAM, 2017, p. 45).

Measures to achieve the sectoral reduction targets are specified through Sectoral Mitigation Action Plans (Planes de Acción Sectorial – PAS) which were developed under Colombia's Low Carbon Development Strategy. The housing sector has its own PAS. The implementation of the PAS is guided by 4-year National Development Plans and sectoral regulations. The primary regulation in this context is the Sustainable Construction Guide, which came into effect along with the Government Resolution 0549. The guide sets an energy performance benchmark for both residential and commercial buildings across Colombia. Depending on the climate zone, the guide prescribes a reduction in energy consumption of between 25% and 45%, although this reduction is voluntary for lower income publicly supported housing in strata 1-3. According to the second Biennial Update Report (BUR), the regulation has the potential to reduce overall emissions by 0.18 $MtCO_2e$ from projected levels emissions in the year 2030 (Colombia *et al.*, 2018, page 226). The BUR however notes that the projected 2030 baseline is currently undergoing revision and is subject to change.

Buildings represent approximately a fifth of the total energy use in Colombia (Government of Colombia, 2013). Furthermore, the Colombian residential buildings' sector emitted 4.7 $MtCO_2e$ in 2014, which is about 4.4% of the country's total emissions excluding agriculture, land-use and forestry sectors. Emissions from the sector are expected to increase in the next two decades by 3.3% per year, reaching 17 $MtCO_2e$ in 2040 (MVCT, 2014). The main energy consumption sources in Colombian households are cooking, refrigeration, television, and lighting, although this varies according to climate zone. In hot and humid climate zones, air conditioning represents a significant portion of household energy demand. In terms of fuel use, electricity represents 55% of fuel use, followed by natural gas (mainly for cooking) at 35% and a small share of Liquified Petroleum Gas (LPG) (UPME, 2017).

Compared to other countries, buildings in Colombia contribute comparatively less to total emissions. This can be attributed, in part, to the relatively clean power generation mix, which has historically been dominated by hydropower. However, increasingly variable rainfall patterns due to the El Niño-Southern Oscillation have led to water shortages in reservoirs and therefore reduced hydropower capacity. The reduced reliability of hydropower in Colombia has prompted calls for expansion of new coal power generation capacity, though an expansion of renewables is also a fast-growing trend. Future emissions projections point towards continued emissions growth through 2050 (Calderón *et al.*, 2014). As energy demand is expected to grow to support economic growth and development, and considering transport is likely to become a larger source of demand for electricity, increased energy efficiency and distributed renewable energy generation in end-use sectors such as buildings will become increasingly important for GHG mitigation.

Beyond GHG mitigation, measures to improve energy efficiency improvement in the building sector have other significant benefits including increased indoor thermal comfort, the promotion of sustainable urbanisation, and lower electricity bills for households. Moreover, energy efficiency improvements can substantially reduce the Colombian government's fiscal burden as electricity and natural gas subsidies for lower income groups constitute large costs to the government.

Improving the energy efficiency of the building sector and promoting renewable energy deployment is a win-win proposition for Colombia. It has the potential to improve construction practices, reduce energy consumption, realise monetary savings both for residents and the Colombian government, increase energy access and security, improve personal health and comfort, as well as reduce emissions.

2.1.1 Emission trends and NDC achievement

The ability and willingness to transfer emission reductions depend on the assumption that revenue associated with the emission transfer enables the transferring country to overachieve its NDC. If the country is not able to achieve its NDC, or if the transfer of emission reductions endangers the transferring country's ability to achieve its NDC, this represents a challenge with regard to participation in Article 6. Approximately 25% of the emission reductions foreseen in the Colombian NDC were expected to come from a reduction in deforestation. This significant share reflects the high contribution of the LULUCF sector to Colombia's overall historical emissions. As Colombia made progress in reducing deforestation from a peak around 2003, it is likely that this share shrunk steadily for a number of years. However, because of a methodological change that improved the granularity of the inventory, the impact of reduced deforestation is somewhat unclear[1] (Lütkehermöller, Luna and Fekete, 2018). Colombian

[1] The Biennial Update Report published in 2015, used global default factors according to tier 1 and 2 guidelines 2006 IPCC. The Third National Communication published in 2017 used tier 2 and three guidelines, which also include local emission factors.

policy makers expected this reduction in deforestation was expected to continue through 2030, but since 2017 deforestation rates have started going up again (Moloney, 2019). An increase in deforestation may make Colombia less confident about reaching its NDC target and therefore more reluctant to transfer emission reductions.

2.2 Logical framework for theory of change

The objective of our virtual pilot is to build capacity and understanding for international cooperation through Article 6 of the Paris Agreement as well as to improve understanding of NZEB technologies' potential in the Colombian building sector.

Together, these are pursued in order to contribute to increased climate ambition in Colombia by helping chart out approaches to decarbonise the building sector and ensure that Article 6 contributes to, rather than detracts from, these efforts. We assessed the feasibility and suitability of using Article 6 to promote the uptake of NZEB technologies that are not yet common practice in Colombia. A theoretical exercise of the change that an actual pilot would seek to bring about is also included but it should be noted that this impact would depend on findings in the virtual pilot. A logical framework overview of this rationale, as well as an actual realised project are outlined in Table 1.

Table 1: Log frame describing rationale for Article 6 pilot NZEB support in Colombia

Impact	Virtual pilot	Actual project (if implemented)
Goal	• Increased climate ambition • Decarbonise the Colombian building sector • Ensure that Article 6 contributes to climate protection efforts	• Increased climate ambition • Decarbonise the Colombian building sector
Objective	• Build capacity and understanding for international cooperation through Article 6 of the Paris Agreement • Build understanding of the potential and application of novel concepts such as net-zero energy buildings (NZEBs) for the Colombian building sector	• Reduce energy demand and GHG emissions • Increase thermal comfort and internal air quality • Leapfrog to best available technologies in building construction • Develop local capacity for sustainable building construction • Increase energy security
Outcomes	• Improved understanding of opportunities and challenges of participating in Article 6 • Improved understanding of potential of NZEBs in the Colombian context	• Reduced GHG emissions • Reduced ppm particulate matter /improved air quality • Popularised electric cooking • Reduced electricity and gas bills • Technicians trained to install and maintain solar PV systems • Improved air quality and thermal comfort of residential units
Outputs	• Virtual pilot report • Presentations on virtual pilot	• Residential buildings that consume no fossil-based energy
Activities	• Desk research • Interviews and consultations • Drafting and publishing of virtual pilot report	• Installation of solar PV panels in multi-family apartments in Cartagena, Colombia • Installation of induction stoves • Installation of high efficiency air conditioners • Well-insulated building envelope • Dedicated outdoor air systems (DOAS) for ventilation and dehumidification

3 Description of the project activity

3.1 Purpose and general description of the project activity

This Article 6 virtual pilot activity aims to explore the feasibility of international cooperation through Article 6 of the Paris Agreement to support the development of new net-zero energy buildings (NZEBs) in Colombia. We take a new housing development in Cartagena, Colombia as a case study for such a prospective initiative.

The virtual pilot will explore the feasibility of using Article 6 of the Paris Agreement to support the development of net-zero energy buildings in the hot and humid climate zone in Colombia. The virtual pilot uses the planned housing project “Puerto Madero” in Cartagena as a case study. The Puerto Madero housing project is a planned Passive House standard residential condominium development on 42 acres of land with a future potential of 2,250 multi-family housing units. Each building is planned to have 6 floors, with 48 apartment units varying from 61 m^2 to 82 m^2 (Consinfra, 2018).

The novelty of the project comes from the fact that both passive houses and net-zero energy buildings are uncommon if not non-existent in Colombia, even in the high-income residential, commercial and institutional segments. This is despite the fact that higher socio-economic groupings (strata 5-6) in Colombia pay a premium on their energy use and should have an added incentive to invest in energy efficient measures, which suggests other barriers to the technology adoption. The Puerto Madero housing project targets strata 3 residents, who recieve various government subsidies. None of these are geared towards improving energy efficiency beyond standard building codes. Notably, strata 3 residents recieve a 15% subsidy for electricity consumption, which serves as a disincentive for energy efficiency.

An NZEB is a highly energy efficient building that meets its energy needs through onsite renewable energy generation (Sartori, Napolitano and Voss, 2012a). Such an approach calls for complete electrification of the building so that no natural gas is consumed and that the building produces as much electricity as it takes from the grid, in our case on a monthly basis. In other words, a net-zero energy building will still be grid connected and use power from the grid but the ‘net’ energy imported from the grid over any given one month period is zero.

3.2 Location of pilot activity

Our investigation focusses on Cartagena, located in the hot and humid climate zone along Colombia’s Caribbean coast.

For our case study, we have investigated the feasibility of an Article 6 pilot based on Puerto Madero in the city of Cartagena, situated on the Caribbean coast in the hot and humid climate zone. Although building net-zero energy housing would make sense in general in Colombia, distinct climatic zones in Colombia require different solutions to make indoor temperature, fresh air, and humidity levels comfortable. In the hot and humid climate zone on the Caribbean coast, mean temperatures fluctuate between around 25-31°C year-round, with 80% humidity. This leads to high levels of energy demand for cooling[2], especially compared to more temperate climate zones in Colombia such as the higher altitude mountainous areas including Bogota.

Cartagena is the sixth largest city in Colombia in terms of population, with over a million residents (Central Intelligence Agency, 2017). It has an expanding middle class and growing residential housing

[2] The Colombian government cites Fanger (1970) to suggest a targeted thermal comfort range of between 21°C and 25°C with a humidity level of between 20% and 75%.

market. However, Cartagena currently faces a housing deficit for the socioeconomic strata 3 and 4 (Straus and Cristancho, 2018).

Cartagena's rapidly expanding middle class, housing deficit, and disproportionately high energy consumption and costs as compared to other major cities makes it an attractive location to develop a highly efficient housing pilot project.

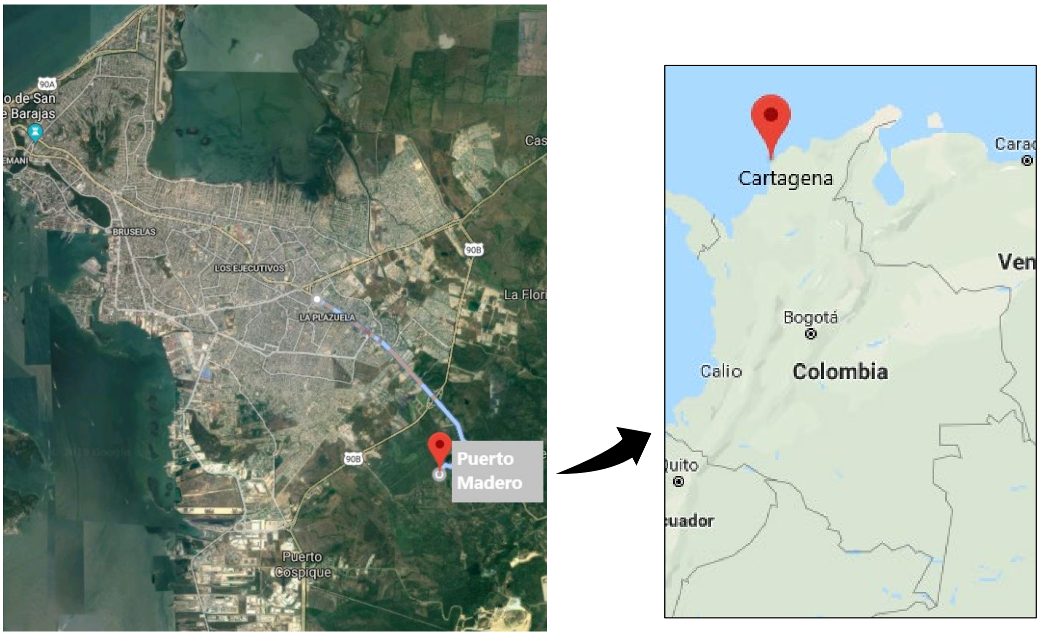

Figure 1: Map of Colombia, the red pin indicates the location of Cartagena (map data ©2019 Google, INEGI)

3.3 Public funding of project activity

There is no public Colombian funding available to real estate developers to incentivise housing construction that goes beyond minimum building code requirements. However, the project will support a reduction of electricity and gas demand from affected households, and therefore of energy subsidies that the government must pay. This means that in the future, the Colombian government may have some interest in the promotion of NZEB housing.

3.4 Technologies and measures

Net-zero energy building: concept and design

A building's energy demand depends on several factors including: the building envelope design (e.g. orientation and exposure to sun and airflows, type of building material, the use of natural ventilation; amount of insulation used, air tightness); energy efficiency of appliances, number of occupants and occupant behaviour.

We draw on Sartori et al. (2012) to define an NZEB as a building that feeds the same amount of electricity, measured in kilowatt hours (kWh), back into the grid as it produces. As in the case study, although natural gas is generally used for cooking in Colombia, cooking would be electrified. In order to achieve a net-balance between electricity use and onsite electricity production, the proposed pilot would optimise both passive (structure and building design) and active aspects (efficiency of appliances and use) and add an onsite electric photovoltaic system to cover residual demand.

Technologies and measures in the NZEB pilot

Based on the typical energy use profile of the Colombian housing sector, a literature review of technological options for NZEBs (Marszal *et al.*, 2011; Nikolaou, Kolokotsa and Stavrakakis, 2011; Sartori, Napolitano and Voss, 2012b; Sartori, Noris and Henkel, 2015; D'Agostino *et al.*, 2016), and the actual Puerto Madero case study, we identified a number of measures necessary to reach NZEB status in Cartagena. These are outlined in Table 2.

Table 2: Design features of a baseline building, planned passive house measures, and an NZEB

<table>
<tr><th></th><th>Design features baseline building (Sustainable Construction Guide compliant)</th><th>Design features of planned Puerto Maduro Passive House Project</th><th>Design features NZEB</th></tr>
<tr><td>Building orientation</td><td>No optimisation of building orientation and shading system</td><td colspan="2">Optimised building orientation and shading system</td></tr>
<tr><td>Shading System</td><td>No shading or sun protection</td><td colspan="2">Window shading</td></tr>
<tr><td>Wall insulation and air tightness</td><td>No insulation of walls or roof, no extra air sealing</td><td colspan="2">Building envelope insulation and air sealing</td></tr>
<tr><td>Window efficiency</td><td>Single glazed aluminium windows</td><td colspan="2">Double pane energy efficient windows</td></tr>
<tr><td>Ventilation and humidity control</td><td>No mechanical ventilation and dehumidification system</td><td colspan="2">Dedicated Outdoor Air System (DOAS) that includes automatic ventilation with heat exchanger with a dehumidification function</td></tr>
<tr><td>Lighting</td><td>Some CFL, though increasingly commonly LED</td><td colspan="2">LED lighting</td></tr>
<tr><td>Air conditioning</td><td>Large capacity air conditioning units with average energy efficiency</td><td colspan="2">Smaller air-conditioner (A/C) units – passive measures enable a reduction in necessary system size</td></tr>
<tr><td>Clothes dryers</td><td>Vented clothes dryers</td><td colspan="2">Non-vented heat pump based condensing clothes dryers</td></tr>
<tr><td>Cooking</td><td>Natural gas-based cooking</td><td>Switching from natural gas to electric coil stove top for cooking</td><td>Switching from natural gas to efficient induction electric cooking</td></tr>
<tr><td rowspan="2">Energy sources</td><td>Grid supplied electricity</td><td>Grid supplied electricity</td><td>Grid connection and Solar PV</td></tr>
<tr><td>Grid supplied natural gas</td><td colspan="2">Elimination of natural gas use</td></tr>
</table>

Passive energy efficiency measures

The case study optimises building orientation to reduce the surface area exposed to sunlight and adds window overhang for shading in order to reduce solar radiation coming directly into the building. Conventional buildings in Colombia are generally built without the architects or construction companies taking consideration of building geometry and orientation.

The Puerto Madero case study will have wall insulation of 15 cm with a U-value of 0.22, and double pane windows with a U-value of 1.94 W/(m^{2}K). U-values represent a heat transfer co-efficient measured in watts of heat per square meter kelvin – the lower the value the better, as less heat is transferred. A solid brick wall will commonly have a U value of 2 W/m^{2}K, while a single pane window 4.8 to 5.8 W/m^{2}K (Designing Buildings, 2019). Conventional buildings in Colombia use aluminium single pane windows without thermal breaks and include no wall insulation, regardless of the climate zone the building is in.

Building air sealing in hot and humid climate zones helps reduce the amount of hot and humid air that leaks into a building, therefore reduces cooling energy demand and costs. Although behavioural factors such as how often doors and windows are left open can undermine efficiency, even in a relatively airtight building, air sealing can enable efficiency compared to conventional buildings in Colombia (which are not sealed against air leakage).

Active energy efficiency measures

Because of the improved building envelope performance and air sealing, alternative ventilation is needed to ensure a flow of fresh air to building occupants. Globally, highly efficient dedicated outdoor air systems (DOAS), that provide fresh air through mechanical ventilation and featuring heat exchangers, are available to keep indoor temperatures cool as well as maintain lower humidity levels inside through dehumidification. In the Puerto Madero case study, they use a Swegon DOAS system. Air inflow is planned for bedrooms and living rooms, extraction is planned for the kitchens, bathrooms and other areas of the housing units. Again, standard buildings in Colombia rely on open doors and windows as well as a lack of air sealing for fresh air from the outside and are not efficient in maintaining a difference between inside and outside heat and humidity levels. The Passive House Institute has certified the Swegon DOAS system for use with the Passive House Standard (Swegon, 2019).

The passive energy efficiency measures and the DOAS mechanical ventilation and dehumidification system do not completely eliminate the need for air conditioning to cool the buildings but do reduce the size and cost of the system needed. For the virtual pilot we assume energy efficient air conditioning systems with hydrocarbon (non-CFC) refrigerants.

Efficient light emitting diode (LED) lighting will be installed in the pilot. This is however likely not additional as Colombia banned the sale of incandescent light bulbs after December 2010. While there was some uptake of compact fluorescent lights (CFL), the cost of LED lighting has gone down significantly both globally and in Colombia and gained large market share. In addition to generally being more energy efficient, LEDs also help to keep cooling demands low due to reduced heat radiation compared to conventional incandescent or halogen lighting.

Heat pump based condensing clothes dryers are included in the virtual pilot as an alternative to conventional venting clothes driers. Conventional vented clothes dryers recirculate hot humid air either into the environment, or need an external vent that undermines the air tightness of the building envelope (Cascade Built, 2019). While largely a cultural issue, Colombians have a strong cultural preference for having their own washing machine and dryers and are resistant to hang drying on racks and communal laundry facilities. A communal laundry facility is seemed as a detraction when Colombians consider buying real estate. In contrast, communal laundry rooms are common in large buildings in the United States.

Fuel switch

Natural gas is the main cooking fuel in Colombian urban households and new construction also generally plans for natural gas cooking. The virtual pilot housing includes efficient electric induction cooking stove tops. Induction cookstoves represent the most energy efficient cooking technology, where instead of indirect radiation, convection, or thermal conduction, a magnetic field is used to produce heat directly in the metal base of a pot or pan. This greatly reduces waste ambient heat and makes induction cooking both the most efficient cooking option (Sweeney *et al.*, 2014) and allows for reduced demand for cooling in hot climate zones. Using renewable electricity makes cooking GHG neutral.

Onsite renewable energy generation

Onsite electricity generation is included in the virtual pilot in order to generate electricity to reach net-zero or near net-zero status. Multi-story buildings have limited rooftop space per apartment unit to install solar PV, so inclusion of further options to increase solar PV capacity may be necessary. Solar carports or solar PV installed on parking structures are fitting applications. Cartagena receives an average daily solar radiation of 5,654 Wh/m^2 , whereas Stockholm receives less than twice as much – approximately

2,689 kWh/m^2 (Global Solar Atlas, 2019). Despite relatively high electricity prices on the Caribbean coast in Colombia, residential solar installation is in its infancy though net-metering installation has recently been introduced (Ministerio de Minas y Energia, 2018). For the PV system used in our case study, we estimate that the roof of the building is sufficient to cover about 70% of the entire PV system size, while an additional 30% of the system would need to be installed elsewhere such as on the roof of carports or garages.

4 Methodologies and baseline

4.1 Methodology

We draw on a number of different sources to inform calculations for the baseline and project emissions. The CDM methodologies AMS-III.AE on 'Energy efficiency and renewable energy measures in new residential buildings' (UNFCCC, 2018a) (further referred to as AMS-III-AE) and the CDM "TOOL31 Methodological tool: Determination of standardized baselines for energy efficiency measures in residential, commercial and institutional buildings Version 10.0" (UNFCCC, 2018b) (further referred to as TOOL31) serve as a starting point. It is noteworthy that no CDM project has yet been developed with the AMS-III.AE methodology. Adjustments for baseline determination and assumptions in the context of the Paris Agreement taking Colombia's NDC into consideration are discussed below.

Although actual sampling for baseline determination was not possible for the virtual pilot and would need to be for actual project development, we provide an ex ante estimation of emission reductions using the 'PHPP tool' developed by the Passive House Institute[3] (Passive House Institute, 2015) to develop an estimation of the baseline and mitigation case, followed by a discussion of necessary adjustments to account for various factors. The input building and energy data comes from the Puerto Madera Passive House building developers.

4.2 Project boundary, sources and greenhouse gasses

For the proposed NZEB pilot, the physical boundary includes the area of the building structure as well as adjacent areas that will be used for the installation of additional PV panels.

Within the scope of the emissions calculation, we include CO_2 emissions associated with both electricity and natural gas consumption for reference baseline buildings. Electricity is used for cooling, lighting, refrigeration, and various other electronic appliances (televisions, mobile telephones, etc.). Natural gas is the primary fuel used for cooking. Especially in hot and humid climate zones, residential buildings do not generally include hot water heating systems.

Not considered within the scope of the emissions calculations are embedded emissions in the building materials, emissions associated with the construction process, fugitive emissions associated with gas cooking, or possible hydrofluorocarbon (HFC) fugitive emissions from refrigeration and air conditioning. According to the project developers, the Puerto Madero project does not call for any additional steel or concrete compared to a conventional building - .The main additional material is EPS (Expanded Polystyrene) for insulation, which they say is the lowest possible embodied carbon insulation available. The windows are double pane, which increases embedded emissions compared to single pane windows, but the building window to wall ratio is lower than for conventional buildings. The concrete is reinforced with standard rebar. No steel beams are used in the project. The Passive House Institute is

[3] The Passive House tool, while containing data on both heating and cooling, was originally designed for climate zones where heating is more relevant than cooling. While it contains all relevant calculations, it has not been applied frequently in the context of a hot, humid tropical climate.

looking into further opportunities to reduce embedded emissions in building materials. There is insufficient research into the lifecycle of NZEBs in general and any calculations rely on a number of assumptions, importantly the supply chain of the building materials and the lifespan of the building which will vary significantly from building to building and place to place.

We are also very aware of the embodied energy of building materials and the high embodied energy that concrete and steel have, but for this type of structure and climate we do not see any other material that can make the project feasible.

Fugitive emissions associated with gas cooking would be eliminated in a switch to electric induction cooking. These methane emissions are however excluded because quantification of these reductions is particularly challenging given the diversity of gas stoves available on the market and uncertainty with regard to their installation and maintenance. We do however include CO_2 emissions from the combustion of natural gas use in cooking.

Fugitive emissions from refrigeration and air conditioning are a source of potential F-gas emissions (e.g. HFCs). Refrigerators and air conditioning units, depending on the refrigerants used, may release potent greenhouse gasses, especially in the event of improper disposal. A NAMA focussing on refrigeration in the country is working on building production lines for refrigerators using hydrocarbons instead of HFCs as coolants. The pilot will seek to employ refrigerators and air conditioners that use hydrocarbon coolants, but any reductions in this respect are also considered outside the scope of the virtual pilot.

The main sources of emissions and GHGs covered in the baseline and project scenario are provided in Table 3.

Table 3: Reasoning for inclusion of GHGs in the estimations. Only orange items are included.

Scenario	Source	Gases	Included	Explanation
Baseline	Power plants connecting to the electricity grid providing electricity to a baseline residential building	CO_2	Yes	Major pollutant
		CH_4	No	Minor pollutant
		N_2O	No	Minor pollutant
	Fuel consumed for energy generation purposes (cooking)	CO_2	Yes	Major pollutant
		CH_4	No	Minor pollutant
		N_2O	No	Minor pollutant
	Air conditioning units	CFCs / HCFCs / HFCs	No	Assumption of minor pollutant
Pilot/project	Power plants connecting to the electricity grid providing any residual electricity to a building in the pilot	CO_2	Yes	Major pollutant
		CH_4	No	Minor pollutant
		N_2O	No	Minor pollutant
	Air conditioning units	CFCs / HCFCs / HFCs	No	Assumption of minor pollutant

4.3 Contribution to decarbonisation (Paris alignment)

We propose three questions to determine whether an Article 6 activity supports the Paris Agreement's ultimate objective of decarbonisation:

1. Does the project involve continued use of fossil fuels?
2. Is there a danger that the project becomes a stranded asset in a rapid sectoral decarbonization scenario?
3. Does the project contribute to transformational change?

The proposed NZEB pilot does not involve continued use of fossil fuels on site. The pilot activity aims to electrify cooking so as to eliminate consumption of natural gas and generate enough renewable energy on-site to cover the power needs of households on a net basis. Disregarding potential mismatches between renewable electricity generation and household electricity consumption timing issues, on a net-basis this should eliminate emissions associated with electricity use from the grid.

We do not foresee any danger of an NZEB becoming a stranded asset in a rapid sectoral decarbonization scenario. Rather, an NZEB pilot can be regarded as a role model for rolling out net-zero energy building concepts in Colombia and support sectoral transformation. We understand 'transformational impact' to reasonably answer the question: How does the mitigation activity have a larger effect on the sector that is in line with achievement of the Paris temperature goal? Transformational impact of an intervention can be differently defined for different sectors/types of activity.

Sectoral transformation of the building sector must aim for decarbonisation. This requires that the energy use from buildings is minimised and that all remaining energy demand is generated from renewable sources, either on site or through a decarbonized electricity grid. Progressive countries, regions, and cities are already moving in this direction and have set concrete buildings targets. For instance, EU regulations require all new buildings to be nearly zero energy from the end of 2020 (European Union, 2018) and, in California, all new single-family homes and low-rise multi-family buildings are to cover their expected annual electricity use on a net basis through the use of rooftop solar to achieve "zero-net electricity" per building from the beginning of 2020 onwards (California Energy Commission, 2018; Delforge, 2018).

Policy developments in the Colombian building sector are moving in the right direction but are far from enough to push the sector towards NZEBs. With its Resolution 0549, the Colombian government made a first attempt to survey households' energy consumption and practices. Policy makers acknowledge the need for better data collection and monitoring. Another positive step forward was taken under the Colombian government's National Economic and Social Policy Council (CONPES) for sustainable buildings of 2018 which defines a roadmap for the building sector by setting the goal for all 'new buildings' to comply with 'sustainability criteria' by 2030 (National Department of Planning, 2018). Improved energy performance targets are expected to be part of the criteria. However, it remains unclear how ambitious these will be and functional examples of net-zero energy concepts in Colombia are missing.

Given the novelty and extra cost of an NZEB (both perceived and real) compared to current practice, Colombian construction companies generally do not have experience in holistic NZEB concepts, techniques, and technologies. The pilot will leverage experience from other parts of the world where NZEBs have been developed to build capacity among architects, construction companies, finance institutions, and housing buyers. With increased scale, costs are expected to decrease while the pilot is only expected to last for a limited time to support ambitious early adopters.

Moreover, while individual single mitigation measures could feasibly be carried out by countries (e.g. insulation, induction cooking, PV, and LED lighting), they overlook the inter-connectedness of different energy uses. An NZEB pilot is likely to suitably demonstrate ambition and transformational impact by setting an example and removing barriers and, together with a larger policy roadmap towards increasingly stringent energy efficiency standards, put the Colombian building sector on a path towards decarbonisation and significantly reduced future energy demand.

4.4 Determination of the baseline

Baselines represent a measure of emissions in a case where an intervention would not have taken place. Determining a baseline from which to measure reductions is a fundamentally important exercise to ensure environmental integrity, make assumptions of additionality, and avoid over crediting. This requires a clear and accurate understanding of the current situation and a robust evaluation of how emission trends are likely to develop in the future. Given the number of factors affecting energy use in buildings and the emissions intensity of energy in the building sector in Colombia, this process is particularly challenging. Notable factors include current and future likely policy measures to improve building efficiency, the effective implementation of those policy measures, energy performance standards for household appliances, the grid emission factor, and future developments in energy consumption behaviour patterns in private households. In the following, we discuss the current situation, as well as trends and potential future developments that may affect a baseline.

Current situation

An initial estimation of the baseline was done with the help of the 'PHPP tool' developed by the Passive House Institute (Passive House Institute, 2015). Information regarding current practice come from information from interviews, visits to construction sites, and model houses built for sales exhibition purposes. Construction practices in the residential sector typically do not consider building orientation with regard to sun exposure or wind direction, use single brick or concrete slab construction without insulation, single pane aluminium framed windows with no shading, and open vents for air circulation around gas stove areas. Households use natural gas for cooking and are usually not equipped with hot water. This housing practice does not have a large effect on energy consumption of buildings in moderate climate zones such as Bogota, the largest city, where there is limited need for heating and cooling as average temperatures are 13-14°C year-round. However, energy use patterns are quite different in different climactic zones and in the hot and humid climate areas along the Caribbean coast, air conditioning is a significant additional source of energy demand. Despite this important distinction in climate, building practices are not significantly different in the hot and humid climate zone compared to the temperate climate zone of Bogota.

The CDM TOOL31 provides a starting point to approach baseline determination. For comparability, the tool calls for sampling of buildings in the same category, in our case multi-family residential high rises of a similar height in the same climatic zone with similar socio-economic conditions of the area where the project will be located (strata 3). TOOL31 calls for the average specific CO_2 emissions from the top 20% best performing buildings in the same building category over the applicable data coverage period for new and existing buildings. While actual sampling is not possible within the scope of the virtual pilot, we discuss available information that could be drawn upon for a preliminary estimate.

The Colombian Sustainable Construction Guide from 2015 estimates that average energy consumption for non-social housing in the Colombian hot and humid climate zone to be 50.2 kWh/m^2 per year without the application of a number of energy efficiency measures prescribed by the government (MinVivienda, 2015). These numbers are a large departure from both the calculations made with the Passive house tool for our case study – which estimates energy use by using detailed bottom-up calculations and from other statistical information on energy use (see Table 4). Although this is not made transparent in the guide, a possible reason for the discrepancy could be that cooling energy use has not been considered. While the use of air conditioning is common in the climate hot and humid zone, they are often generally added by the residents themselves rather than being planned and installed by the construction company from the outset. Colombia does not have minimum energy performance standards (MEPS) for air conditioners, so in practice, a variety of air conditioners are installed. Even two air conditioning units in the same housing unit may vary greatly in their energy efficiency. There are however a large number of other factors that may influence such energy use patterns, including weather conditions, varying number of occupants per household, time spent in the residence, amount of time windows are left open, number of rooms that are cooled (if any) and energy efficiency of appliances.

Table 4: Estimations of energy use per square meter

	Monthly (kWh)	Yearly (kWh)
Average 2012 per capita electricity consumption strata 3 - National (Osma-Pinto *et al*., 2015)	250.7	3,008.4
Average 2018 per capita electricity consumption strata 3 - Cartagena (SSPD - Superintendencia de Servicios Públicos Domiciliarios, 2019)	283	3,396
Average per capita electricity consumption based on bottom up calculation with assumptions for PHPP tool for the case study $\mathit{Per\ occupant\ electricity\ consumption} = \frac{76.13 \times 3334m^2}{88\ occupants}$	240.35	2,884.28
Average per capita electricity consumption Sustainable Building Guide using assumptions from building in the case study $\mathit{Per\ occupant\ electricity\ consumption} = \frac{50.2\ kWh/m^2 \times 3334m^2}{88\ occupants}$	158.4	1,901

The estimated energy savings with the measures prescribed by the government for general housing (non-social housing) is 45% starting in 2016. Based on stakeholder comments including from the Colombian Sustainable Building Council,[4] the energy-use baselines created for the various building segments under Resolution 0549 are imprecise because they are based on small sample sizes – in some cases only one building type per climate zone. Actual building practices however can vary greatly from construction company to construction company and from building to building. Policy makers are aware of the limitations of the calculations made and are in the process of reviewing the resolution's baselines. An independent baseline setting exercise for Bogota concluded that some of the prescribed measures were already common practice and that a further 5-10% increase in Resolution 0549's targets is possible for all housing categories in the city at an additional direct cost of 0.7%-1.6%[5].

[4] https://www.cccs.org.co/wp/

[5] CCCS's presentation at workshop organized as part of a German Emission Trading Authority (UBA) supported project preceding the SEA virtual pilot study, in Bogota in March 2018

For the calculations performed here with the 'PHPP tool' developed by the Passive House Institute, we have considered the parameters as shown in Table 5.

Table 5: Puerto Madero case study parameter inputs for the PHPP tool

Parameter	Technical details – baseline assumptions PHP tool
Parameter specific to the building type evaluated	
Geographic location of the building	Cartagena, Colombia
Floor area of building	3,334 m²
Number of dwelling units in building	48
Number of occupants	88
Climatic conditions	Hot, humid, tropical
Parameter specific to the baseline	
Wall/ roof and Slab composition and U-value	**Wall**: 10 mm thickness, concrete, U-value of 4.576 W/(m²K) **Roof:** 10 mm thickness, concrete slabs or fibre cement roof tiling, U-value of 3.868 W/(m²K), no insulation
Window type and U-Value window	Single glazed, INCOLORO 6 MM, Aluminium frame without heat bridge, U-value of 5.85 – 5.91 W/(m²K)
Building orientation	No optimization of building orientation and shading system
Air conditioning	Standard air conditioning unit
Ventilation and humidity control	No mechanical ventilation and dehumidification system
Clothes dryers	Vented clothes dryers
Cooking	Natural gas-based cooking
Energy sources	Grid supplied electricity
	Grid supplied natural gas
Window ventilation air change	5 1/h

Using the above parameters, the PHPP Tool provides an energy use figure of approximately 76 kWh/m² excluding cooking (see Table 6). This does not take the mandated energy efficiency measures of the Sustainable Building Guide into consideration.

Table 6: Results PHPP tool Energy use baseline

Baseline - as provided by passive house tool	Value	Unit	Description
Electricity use appliances (excl. cooking)	15	*kWh/m² per year*	*final demand electricity*
Electricity use cooling	61	*kWh/m² per year*	*final demand electricity*
Electricity use (total)	76	*kWh/m² per year*	*final demand electricity*
Gas use cooking	3	*kWh/m² per year*	*final demand gas*

Policies to be considered in baseline projections

In addition to a reform of the Sustainable Construction Guide and the expected baseline revision, the CONPES strategy for sustainable buildings in March 2018 is a policy measure that will likely have an effect on future energy efficiency of buildings in Colombia. CONPES strategies outline governmental goals in a particular field and reflect high level "consensus" among different Ministries – their implementation is supervised by National Planning Department (DNP). The CONPES strategy for sustainable buildings lays out a process to define sustainability criteria for new buildings to 2030. The Ministry of Housing, Cities and Territories (MinVivienda) will oversee the definition of the sustainability criteria, with the support of the Environment Ministry and Mineral Energy Planning Unit of the Energy Ministry (UPME). According to the CONPES, these criteria should be issued in a decree or resolution of the Ministry of Housing. The timetable established in the CONPES provides that the criteria will be formulated between 2019-2020. It is currently unclear how ambitious these measures may be or the extent to which they will be effectively implemented.

Other policies that may have relevance to the future development of emissions in a baseline scenario include the introduction of energy performance standards for household appliances and the uptake of the new net-metering policy, among others. An overview can be found in Table 7.

Table 7: Overview of targets and policies in Colombia relevant to the pilot

Policy / Regulation	Description
Sectoral Action plan for mitigation in housing and territorial development (PAS) (2014)	The PAS estimates the emission reduction potential of the residential sector to be 38 $MtCO_2e$ accumulated until 2040, through activities in two priority areas: a) energy efficiency of appliances; and b) promoting sustainable construction. No concrete targets are defined.
CONPES "Sustainable Buildings" (2018)	CONPES are policy documents outlining governmental goals. The "Sustainable Building" CONPES sets goals for 2030 for all new buildings to comply with sustainability criteria covering building lifecycle, including building energy efficiency. These criteria are currently under discussion.
National Development Plan 2018-2022	The National Development Plan 2018-2022 was approved in 2019. "Housing and worthy surroundings" and sustainable buildings are a strategic priority.
Resolution 0549 and its Sustainable Construction Guide (2016)	Set targets to reduce specific energy consumption in new housing between 25% and 45% according to climatic zoning. The guide is planned to be reviewed every two years. The first revision was due in 2018 and was expected to lead to revision of targets. No revision has taken place yet.
Technical regulations for labelling (RETIQ)	Establishes a labelling scheme for domestic refrigeration, air conditioning, ballasts for fluorescent lighting, washing machines, and cooking appliances. However, inefficient appliances are not phased out. This could be fairly easily converted into MEPS.
Net-metering policy (CREG resolution 030/2018 of March 2018)	Establishes a net-metering policy for households to sell excess energy to the grid, which will improve the financial viability of residential PV even in the absence of a pilot. Detailed rules have however not yet been finalised.

Grid emission factor

Thanks to Colombia's relatively large hydroelectric resource capacity, the emissions intensity of electricity in the country is relatively low. In 2015, hydropower represented 65% of the total electricity production, gas 19%, and coal 12%. Wind power produced a statistically insignificant amount (IEA, 2016a). According to the Colombian Ministry of Energy and Mining, the marginal emissions intensity of the Colombian electricity grid for use for CDM projects is 374 gCO_2e/kWh (MinMinas, 2014). This however was based on an assumption for the next power station likely to be built, based on that last few recent power plants built. This is significantly higher than IEA data which shows a variation of the overall average grid emission factor (see Table 8), but constantly lower.

Table 8: Emissions per kWh of electricity (gCO_2e per kWh)

2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
129.3	109.0	178.1	180.7	105.6	123.8	192.6	218.5	215.8	220.2

(Source: IEA, 2018)

While hydropower is currently an important energy source in Colombia, changing El Niño–Southern Oscillation patterns and associated droughts are likely to reduce future hydropower potential (Dennis, 2015), or at least make it less predictable. The future of Colombia's low carbon electricity mix is therefore unclear. Although uncertain, we take the 2016 IEA value as a medium value since it is hard to predict if the grid emission factor will get dirtier or cleaner.

It is possible that the grid will get dirtier. Colombia has large coal resources, and there are a number of coal-fired power plants with a total of 1,575 MW in capacity currently in the planning stage (Evans, 2019). Presently, Colombia lags behind regional neighbours in renewable electricity investment (Flavin *et al.*, 2014; WWF, 2014), but it is also accelerating the development of renewable energy. At the 2019 UN Climate Action Summit, the Colombian Energy Minister Maria Fernanda Suarez announced a Latin American pledge to collectively[6] increase their renewable energy mix to 70% by 2030, of which Colombia intends to contribute 4 GW (Volcovici, 2019). Colombia enjoys abundant wind, solar, and geothermal resources (Procolombia, 2015) and the region of la Guajira in particular has large potential for wind power development in the country (Norton Rose Fulbright, 2017; Vergara, Deeb, Toba, Cramton, & Leino, 2010). In 2016, Colombia announced plans to increase installed wind capacity by over three GW by 2029 (Barrero, 2016), representing a significant portion of the 4 GW 2019 pledge. Several large wind projects are already in the project pipeline in the north of the country (Mergermarket, 2017). Empresa de Energía de Pacífico (Epsa) announced in July 2018 that it would float bonds for non-hydro renewable energy projects, including a 185 MW tranche worth divided in four PV solar projects. These four projects are expected to produce 312 GW hours per year (The Dialogue, 2018). A 2019 government resolution will require power distributors to have at least 10% of the power they distribute coming from renewables that are procured through power purchase agreements of at least 10 years starting in 2022 (Bellini, 2019a). The Colombian government is further bundling procurement of large scale solar and wind parks through regular auctions (Bellini, 2019b). However, the potential of using the existing hydro as a complementary back-up capacity for solar and wind power has not been exploited.

Energy subsidy reforms

Pricing and subsidies for residential consumption of energy play an important role in influencing consumer behaviour with regard to energy use. Since the mid to late 1990's, the Colombian population has been loosely organised into six socio-economic groups or strata *(Stratos)* first codified by the Law 142 of 1994. Rather than being based on income directly, these groupings are mostly geographical and are related to access to public services and building features (OECD/ECLAC, 2014; Guevara and Shields, 2019). The government subsidises power, gas and water consumption as well as telecommunications services in lower strata (Strata 1, 2 and 3), partially offset by a premium on the price of these services paid by strata 5 and 6. This subsidy system has however gone through a number of reforms since its introduction. Until December 2017, the government subsidised energy consumption of strata 1-3 without limit. Article 104 of Law 1873 of 2017 placed a cap on the subsidised portion corresponding to a "basic consumption level" of 173 kWh for hot climate zones below 1000 meters in altitude, and 130 kWh for areas above 1000 meters (MinMinas, 2004; MinJusticia, 2017). The lower strata represent 88% of all electricity subscribers and is growing quickly.

Table 9: Electricity subsidy according to socio-economic grouping (strata)

Strata	Subsidy
Strata 1	60% of general tariff for basic consumption level
Strata 2	50% of general tariff for basic consumption level
Strata 3	15% of general tariff (regardless of consumption level)
Strata 4	General tariff, no subsidies, no contributions
Strata 5 & 6	120% of general tariff

[6] In addition to Colombia, the pledge was signed by Chile, Peru, Ecuador, Costa Rica, Honduras, Guatemala, Haiti, the Dominican Republic.

Because collected premium from strata 5 and 6 is not enough to cover the subsidy, the government covers the remaining costs. Some households pay less than two thirds of the marginal cost of electricity (McRae and Wolak, 2019). This is a substantial and growing financial burden for the government as energy subsidies to lower strata amounted to as much as 95% of the total budget of the Ministry for Energy and Mining (Bansard, Pattberg and Widerberg, 2016), and disincentivises a fuel switch from fossil fuels to electricity for cooking and electric vehicles for higher earners (McRae and Wolak, 2019). There is therefore an ongoing discussion on reform options, but exactly what these will be and how they will actually influence household energy consumption patterns in different strata is unclear.

Rough preliminary calculation of current emissions

Noting the various current uncertainties, as well as those going into the future, we provide a preliminary estimation of current baseline emissions on the basis of our bottom up calculation.

$$SE_{BL} = \left(EC_{grid} * EF_{grid}\right) + \left(FC_{gas} * EF_{CO2,gas}\right)$$

Where:

EC_{grid} = Grid electricity consumed by the baseline unit. 76.13 kWh/m^2 per year for 3,334 m^2 of floor area, or 253,831 kWh (rounding creates slightly different values).

EF_{grid} = Emission factor of the electric grid supplying electricity to the baseline building unit. Here we use 220 gCO_2 per kWh (latest IEA estimate).

FC_{gas} = Amount of natural gas consumption of baseline building unit. 3 kWh per m^2 per year over 3,334 m^2 of floor area, or 10,002 kWh. Although primarily for cooking, government statistics track natural gas use in kWh per m^2.

$EF_{co2,gas}$ = CO_2 Emission factor of natural gas. 200.05 gCO_2 per kWh (Quaschning, 2015).

SE_{BL} = Specific CO_2 emissions of the baseline building unit. 58,033,685 g (at 220 gCO_2 per kWh.

Suggested further steps required for baseline setting

For robust baseline determination representing a scenario to compare to the project's emissions, one would need to conduct extensive sampling of energy consumption of at least 100 recently built multi-family residential buildings and ensure that they were built to code, including the required measures under the Sustainable Building Guide, before considering the energy use of the 20% best performing buildings. This is an adaptation to CDM Methodology AMS-III.AE (UNFCCC, 2018a), taking the legal requirements of the host country into consideration.

Current statistics on energy use per capita in strata 3 from other available sources do not make a distinction between people living in buildings that comply with the Sustainable Building Guide and those who do not. There is a lack of ex-post verification with regard to whether or not newly built buildings have been built to code and local stakeholders say that the guide's implementation has been uneven at best. It is therefore challenging to conduct an analysis of the energy use of buildings complying with the measures prescribed by the Sustainable Building Guide without on-site inspections to verify that they comply to create a sample for the baseline.

Although this would provide improved information with regard to the current energy use and efficiency of housing, it would require significant further investment associated with high transaction costs, may encounter resistance from residents, and may still not necessarily provide a robust baseline given the challenges of predicting the future development of building construction codes for energy efficiency, the grid emission factor and behavioural responses to future energy subsidy reforms.

4.5 Demonstration of additionality

First of its kind

Passive houses based on a whole house or whole building approach are next to non-existent in Colombia. Going further to make the passive houses into NZEBs is novel in Colombia and in Latin America, with only one known example of a holiday home in Panama (Hoque and Iqbal, 2015). Therefore, we estimate domestic and regional market penetration rates to be 0%.

Identification of alternatives

Based on desk research and interviews with stakeholders in Colombia, although various initiatives and reform processes are underway in the building sector (and considering that it is hard to judge exactly what effect they will have), it is unlikely that there will be a large shift in construction practices without significant intervention. Contemporary building practices are not geared towards the construction of efficient housing, generally do not comply with the Colombian requirements outlined in the Sustainable Construction Guide, and do not result in buildings approaching NZEB status.

Financial additionality

The policy barriers are complemented by financial barriers to energy efficient residential buildings. Local banks such as Davivienda and Bancolombia provide some financial incentives to build and buy more energy efficient housing by means of discounted interest rates for both construction and mortgage financing, funded through a Green Bond that the banks structured with the help of the World Bank's International Finance Corporation (IFC). For example, Bancolombia has a programme in which the loan that housing developers get for energy efficient construction is a full percentage point better than the market rate for construction finance. In addition, homebuyers receive a 0.35% interest discount on mortgages for energy efficient houses (Bancolombia, 2019). This makes some financial sense for the bank because homeowners with reduced monthly energy costs have higher disposable income and are less likely to default on their mortgage payments and therefore represent a lower credit risk for the bank. However, there are no financial incentives to go beyond the minimum Sustainable Construction Guide measures for either builders or prospective buyers. The latter are often unaware of the advantages of energy efficient building measures. Hence, building NZEB multi-family apartments is likely an investment risk for the project developer if there are other developers that offer less efficient, but otherwise similar housing at a lower price.

To determine whether an NZEB would be financially additional, we assessed if it is financially attractive to build an NZEB without the financial support through the sale of emission reductions through an Article 6 framework. Overall costs, including potential revenue and cost savings, are the main factor for this analysis, so we compared the project's costs with the most plausible alternative situation. This analysis allows for a determination of whether it would make sense from the prospective house buyer's perspective to make the necessary investment for an NZEB without external financial incentives. The input information has been provided by the developers of Puerto Madero as an estimate, with an independent bid for the addition of solar PV. Such costs are however subject to considerable information asymmetry- and may vary based on timing, scale, exchange rates, suppliers, and from place to place. Prices are indicated in USD for comparability using a rate of 3,457 Colombian Pesos per US Dollar (the exchange rate in October 2019).

The most plausible alternative for our project is the baseline situation: a similar building complying with the requirements set by the Sustainable Construction Guide under Resolution 0549. The design features of the baseline situation and the NZEB pilot were summarized in Table 2.

Although the additional costs of building orientation and shading are not significant, the other additional upfront costs for the Passive House project in the case study come from additional investment in an insulated building envelope and air sealing, double pane windows, automatic ventilation with heat exchanges including a dehumidification system, and condensing clothes dryers. The added insulation of the building however enables a reduction in the size of the air conditioners needed and therefore represents a cost saving. To make the Passive House project an NZEB, the further addition of solar PV panels is required. An overview of the baseline costs and NZEB features is provided in Table 10.

These measures are not common practice in the region and some elements such as the DOAS are not generally locally available. Double paned windows are however produced by local manufacturers, suggesting the existence of a local market. As of 2019, residential rooftop PV penetration is negligible in Colombia, even in higher strata that pay 120% of the basic rate for electricity (McRae and Wolak, 2019).

In the case study example here, we have included the cost savings of not having to buy an air conditioner from the perspective of the future occupants, although this cost is normally bourn by the occupants when they install window-based air conditioning units rather than by the construction company.

The total expected additional upfront investment cost of NZEB features for the whole building with 48 units in this case study is approximately 363,414.73 USD, or 15.49% higher than the costs for the baseline building. The major challenge posed by the development and construction of the NZEB is the split incentive between the real estate developer and the apartment owner. The real estate developer does not pay for the energy consumed in the house and therefore has no direct incentive to install energy efficient measures. Depending on the needs of the housing unit buyer (location, etc.), they may not have a choice between energy efficient or inefficient housing.

The extent to which the real estate developer can demand at least a 15.49% price premium over comparable real estate options for prospective apartment buyers depends on a number of factors, including prospective buyers’ understanding of the energy efficient cost saving measures, willingness to take the risk of the additional upfront investment, electricity and gas prices, inflation, and mortgage interest rates. Importantly, the income level and socio-economic grouping of the prospective house buyer determines their eligibility for energy subsidies and has a large influence on the ability and willingness to undertake investments that pay for themselves over time.

Currently, the developer Consinfra is building Puerto Madero with various energy efficient measures, working towards passive house standards, but without a number of NZEB features and without the support of an Article 6 approach. This business model is however new and untested in the Colombian market, requiring the real estate developer to conduct an information campaign to inform prospective buyers that the energy efficiency measures are worth the additional cost.

Table 10: Additional cost implications of design features to achieve NZEB status

		Design features	Cost comparison per multiunit building	Difference in USD
Building orientation	Baseline	No optimisation of building orientation and shading system	Insignificant additional cost	
	Case Study	Optimised building orientation and shading system		
Shading System	Baseline	No shading or sun protection	Insignificant additional cost	
	Case Study	Window shading		
Wall insulation and air tightness	Baseline	No insulation of walls or roof, no extra air sealing	-	126,500.00
	Case Study	Building envelope insulation and air sealing	126,500	
Window efficiency	Baseline	Single glazed windows	28,151	177,824.20
	Case Study	Double pane energy efficient windows	205,975	
Ventilation and humidity control	Baseline	No mechanical ventilation and dehumidification system	-	133,261.00
	Case Study	Dedicated Outdoor Air System (DOAS) that includes automatic ventilation with heat exchanger with a dehumidification function and ductwork	133,261	
Lighting	Baseline	Some CFL, though increasingly commonly LED	Insignificant additional cost	
	Case Study	LED lighting		
Air conditioning	Baseline	Air conditioning unit with average energy efficiency	278,097	(- 237,189.00)
	Case Study	Energy efficient air-conditioner (A/C) – passive measures enable a reduction in necessary system size	40,908	
Clothes dryers	Baseline	Non-vented condensing clothes dryers	20,832	28,800.00
	Case Study	Condensing clothes dryers	49,632	
Cooking	Baseline	Natural gas-based cooking	7,296	16,704.00
	Case Study	Electric induction stoves	24,000	
Electricity	Baseline	Grid Connection	-	
	Case Study	100 kW Capacity PV array to cover estimated net electricity demand	117,515	
Total cost	Baseline	Cost of construction plus appliances normal building	2,346,293	363,414.73
	Case Study	Total cost of NZEB features	2,709,708	
			Total additional cost for a 48-housing unit building	363,414.73

For the occupants, as a group, a net present value (NPV) calculation indicates if it would make financial sense for prospective apartment buyers to invest in a housing unit with the additional features of an NZEB building, given the investment costs, current mortgage interest rates, and current inflation rates for the price of electricity and gas. The following formula is used to calculate the NPV of the upfront costs for the NZEB features and the energy savings from not paying for electricity and gas in the future:

$$NPV = \sum_{t=1}^{n} \frac{R_t}{(1+i)^t}$$

Where:

R_t = Net case inflow-outflow during a single period *t*. In our calculation, the initial additional outflow of 363,414.73 USD in the present (*t*=0), and future inflows are represented by the inflation adjusted savings in energy that the residents would not have to buy from the grid (R_t=1, 2, 3, …). For this we take the electricity consumption in the baseline 253,831 kWh, multiplied by 532.38 COP per kWh, adjusted for various strata subsidy levels. For Strata 3, the building in our case study, total baseline electricity costs for the building are 114,864,417 COP a year, or approximately 33,226 USD at 3,457 COP to the USD[7]. The current inflation rate of the cost of electricity is fairly high, at 7.61% in Cartagena (Mouthon, 2019). The elimination of 1238 m^3 of gas for cooking through the electrification of gas stoves brings about a comparatively modest savings of 742 USD per year at a gas price of 2074 COP per m^3 (Gases del Caribe, 2019).

i = The discount rate - or in our case, the interest rate (cost of capital) on the mortgage for the residents, assuming that the additional cost of the NZEB is 100% mortgage debt financed. Current mortgage interest rate range from 6.61% to 14.46%, depending on credit worthiness and the bank (SFC, 2019). For reference, we also show the calculation for interest rates of 10%.

t = The number of years taken into consideration for the investment. The guaranteed lifetime of a PV system is approximately 20 years, although various components will likely last longer. While a housing asset in Cartagena will often last longer than 30 years, it is unlikely that mortgages can be found for fixed interest rate for much beyond that time horizon. We calculate NPV for 5, 10 and 20 years.

The Internal Rate of Return (IRR) describes the interest rate at which the NPV for that time horizon is equal to zero. Interest rates below the IRR indicate when the NPV turns positive and thus the threshold interest rate that is necessary to make the investment worth making. Conversely, interest rates above the IRR will indicate when the NPV turns negative and when it is not worth it from the prospective housing purchaser's perspective to make the investment for the given time horizon.

We assume that the maintenance costs for an NZEB building are similar to a conventional building and exclude any tax advantages such as accelerated depreciation for the equipment. According to our calculations, the NPV of an NZEB is highly dependent on the interest rates that the potential home buyer may be able to get from the bank for their purchase, and what strata the building is in – the strata determines what kinds of energy subsidies the residents get (mainly electricity subsidies). For home buyers in strata 1, who receive the most generous electricity subsidies but are eligible for subsidised mortgage interest rates, the NPV value is below zero across all scenarios under a ten-year time horizon, despite eligibility for lower interest rates. This income group is least likely able to afford the increased debt load for the NZEB features. Where we have our case study, in strata 3, residents are eligible for subsidies, but less generous ones. Here, the NPV is still negative for time horizons of less than ten

[7] Currency exchange rate from Google on 17 October 2019.

years. For strata 4, who do not receive subsidies, a positive NPV would require an interest rate below 7% for 10 years and would save money after the 12th year.

It would however make financial sense for strata 5 to make the additional investment for an NZEB, as at all interest rates they are expected to have a positive NPV in under ten years, primarily because they pay a premium on their electricity rate in order to subsidise the other strata. This would however cause a problem for the Colombian government, because it would have to make up the loss of the premium payments that strata 5 would otherwise have paid. For an overview of NPVs at various interest rates and time horizons, see Table 11.

Table 11: NPV for strata 1, 3, 4, and 5 at various interest rates and time periods

			Interest rate		
			6.61%	10.00%	14.46%
NPV for Estrato 1	NPV 5 years		(-239,508.40)	(-221,694.29)	(-259,431.45)
	IRR	-28%			
	NPV 10 years		(-77,974.47)	(-94,715.20)	(-160,828.96)
	IRR	2%			
	NPV 20 years		305,093.09	120,992.86	26,401.78
	IRR	13%			
NPV for Estrato 3	NPV 5 years		(-224,322.18)	(-234,760.43)	(-246,687.05)
	IRR	-25%			
	NPV 10 years		(-42,990.31)	(-89,052.68)	(-135,999.62)
	IRR	4%			
	NPV 20 years		387,026.80	158,471.02	14,903.23
	IRR	15%			
NPV for Estrato 4	NPV 5 years		(-158,576.82)	(-176,863.64)	(-259,431.45)
	IRR	-21%			
	NPV 10 years		56,049.88	(-9,717.05)	(-75,255.14)
	IRR	7%			
	NPV 20 years		516,563.21	637,641.00	80,206.05
	IRR	17%			
NPV Estrato 5	NPV 5 years		(-118,372.84)	(-140,248.85)	(-164,673.64)
	IRR	-16%			
	NPV 10 years		138,379.13	59,703.97	(-18,697.42)
	IRR	11%			
	NPV 20 years		689,278.42	762,792.20	167,276.48
	IRR	20%			

This suggests that with the electricity rates in the hot and humid climate zone on the Caribbean coast in Colombia, NZEB's only make financial sense over longer time horizons, at lower interest rates for those residents who do not receive subsidies on their electricity consumption. Even for higher socio-economic groups, the investment in an NZEB comes at a risk to the house buyer if real estate values go down, if inflation rates for the price of electricity do not rise, or if they cannot get a fixed interest rate loan for a long period of time. Decanio (1993) finds that even residential measures with rates of return of 30%, 40% or more go unrealised due to barriers such as bounded rationality and principal agent problems.

If however subsidy systems are reformed, and other barriers to NZEBs are removed, they may have potential for fairly rapid uptake in practice. NZEB are least attractive for lower socio-economic groups, though they are already attractive for richer income residents in higher strata who pay a premium on their electricity rate.

Common practice and barriers

To date, the Puerto Madero project is the only Passive House standard project in Colombia. Another innovative project is the 'Fabrica de Cultura' in Barranquilla, a cultural centre which also includes in its design a number of energy efficiency measures; however, itis neither built to passive house standards nor as an NZEB. In the absence of NZEBs in Colombia, a project brings a first-mover risk for the project developer. The proposed pilot goes beyond local practices in the residential building sector and government mandated measures, which focus on marginal changes, rather than requiring a more holistic whole building efficiency approach adding the production of on-site PV.

While knowledge in some building components that are part of an NZEB, such as energy efficient windows or insulated walls, exists and expertise and availability of material in the country can be built upon, this is not the case for all components. The proposed mechanical ventilation with heat exchanger is not locally available, would need to be imported and could benefit from support to increase installation and use in the country. The passive house approach, essential for NZEBs, requires a holistic approach. This is different than just a number of individual measures on their own.

A lack of effective energy efficiency policy implementation and uneven enforcement has led to a continuation of business as usual regarding building practices. The lack of awareness and lack of understanding for potential home buyers means that construction companies not complying with the Sustainable Construction Guide have a comparative advantage in terms of cost, creating a barrier for construction companies interested in promoting highly efficient housing.

The current domestic standards for energy efficiency of appliances is not as conducive to energy efficiency as they could be. Colombia does not have Minimum Energy Performance Standards (MEPS) for appliances, which leads to continued availability of inefficient, lower-cost appliances. The existing labelling requirement is outdated, and energy efficiency levels used in the labelling programme in Colombia have not been upgraded since they were introduced, even though domestic producers can comply with the initial levels (A-C) with ease[8]. This suggests an opportunity for recalibrating the scale. This also means that consumers do not have sufficient information to make a decision to purchase energy efficient appliances based on their superior efficiency.

The discussion above illustrates that the related policy and regulatory environment, as well as the investment climate have not yet been conducive to the mainstreaming of more efficient building construction. This is the case both generally in Colombia, and more specifically in Cartagena, where we find that policies are not effective in moving the sector towards NZEB status (even) despite high local electricity prices.

4.6 Demonstration of inaccessibility

To ensure that the ability to commodify the mitigation outcomes of the project does not present a potential ambition disincentive for the Colombian government when revising their NDC, the project activity must use a technology or a practice that would not otherwise be realistically accessible for Colombia. Inaccessibility is different from additionality, in that additionality considers if the project activity would have happened without the Article 6 intervention given current legal framework, access to finance, common practice, and technological trends. Accessibility on the other hand, considers if an ambitious host country could access the technology without foreign support. Many activities are additional but still readily accessible to the host country given factors like cost and technology maturity. Easily accessible technologies should be left for domestic action towards the host country's NDC or a future ratcheted NDC (NewClimate Institute, 2018). Whether a technology is accessible depends on two factors:

[8] Based on interviews with Unidad de Planeación Minero Energética (UPME), which oversees the labelling programme.

technology costs and technology maturity. Furthermore, the wealth or development status of the host country must be taken into account: a wealthy country can afford more expensive technologies than a least developed country.

Technology costs could include both upfront costs and overall lifetime costs compared to the costs of current technology or the most likely new technology that would be employed if built new. Technology maturity can be assessed based on market penetration rates at the global, regional, and domestic level. Low domestic penetration rates indicate that the country is likely to lack the specific skills and knowledge needed to implement the technology.

If a technology is mature, proven and cheap in one country, it may be considered accessible whether or not it has reached a similar level of market penetration in the given host country. Equally, if a technology is expensive, but has reached a high market penetration in the same region, it may still be considered accessible despite its high cost.

Costs NZEB in Colombia

As shown in Section 4.5, the upfront costs of an NZEB are significantly higher than those for a standard building: 15.49%. Considering that Colombia can borrow on international debt markets for 5-6% (with a ten-year maturity) (Trading Economics, 2019), we find that based on the case study cost estimates, an NZEB building has a negative net present value over a similar ten year time period, also at the lower interest rate of the sovereign. The Colombian government does not currently issue bonds with a 20 year time horizon that would be necessary to test capital markets to see if it would make sense on the national level to support NZEBs with subsidised interest rates backed by the sovereign.

Parallel efforts on the Colombian government's behalf could explore what exactly drives the costs of some of these higher cost measures and investigate how to reduce them. We therefore find that under current conditions, on the basis of the case study example, NZEBs in Cartagena are not readily accessible for Colombia. If Colombia is to consider an NZEB pilot project elsewhere in the country, it should assess how costs change and to what extent financial assistance from other countries is required.

Technology maturity NZEB in Colombia

As mentioned above (see Section 4.5, First of its kind), NZEBs are novel in Colombia and Latin America. A whole-building approach to building planning and construction, taking into account energy efficiency, ventilation and air conditioning, appliances, as well as onsite electricity generation is still new for hot and humid tropical climates.

Globally, NZEBs are most mature in the European Union, where from December 2020 onwards all new residential buildings must be nearly zero energy buildings (Council directive 2010/31/EU, Article 9). Within the EU, the Netherlands is the frontrunner in NZEB social housing projects (rented housing).[9] Indeed, the Dutch market for NZEBs has grown exponentially in the last decade although from a low basis. 90 new NZEBs were built in 2013 and 3,656 are expected to be built in 2019 (Bekkema and Opstelten, 2019). This is still very small in comparison to the whole housing market in the Netherlands. In 2018, NZEBs constituted 2.7% of the total amount of newly built houses in the Netherlands; in 2019 this percentage is expected to increase 2.6 percentage points to 5.3%[10]. In addition, there are several initiatives to refurbish existing buildings to meet NZEB standards. Although the share of NZEBs in the

[9] The NZEB refurbishment programme *Energiesprong* started in the Netherlands as government-funded innovation programme. See: https://energiesprong.org/ (Retrieved 3 June 2019).

[10] Own calculations based on data from the Netherlands Central Bureau of Statistics and Stroomversnelling (2019). See https://opendata.cbs.nl/statline/#/CBS/nl/dataset/82235NED/table?ts=1565604279408 (Retrieved 12 August 2019) and https://stroomversnelling.nl/wp-content/uploads/2019/04/Stroomversnelling-Marktmonitor-NOM.pdf (Retrieved 12 August 2019).

total building stock is still very low, we consider the technology mature in the Netherlands because the expertise to construct NZEBs is relatively widespread.

While the technology might be mature in countries like the Netherlands, there is an important reason why this cannot be easily scaled to tropical regions like Cartagena. NZEB in the Netherlands are mainly focused around reducing the amount of heat that needs to be provided to the inhabitant, while in regions like Cartagena cooling is the factor that drives energy demand. These are quite different questions and cannot be directly compared.

Inaccessibility determination

Current costs are a mixed picture and are highly dependent on energy subsidy policies; they would presently be unattractive to the vast majority of potential home buyers. While the NPV of the additional cost of the investment is better for those who do not receive energy subsidies, the additional cost considering interest rates would likely only make sense over a time horizon of over ten years. The low market penetration of NZEBs in Colombia and in Latin America indicates that Colombia lacks the specific skills and expertise that are needed to implement the practice and that NZEBs are probably inaccessible to the country. For this reason, Colombia could likely justify the need for international assistance to build net-zero energy buildings in hot and humid climate areas. It may make sense for Colombia to engage in such support through Article 6 (see Figure 2) but it should also work in parallel to address perverse incentives created especially through electricity consumption subsidies.

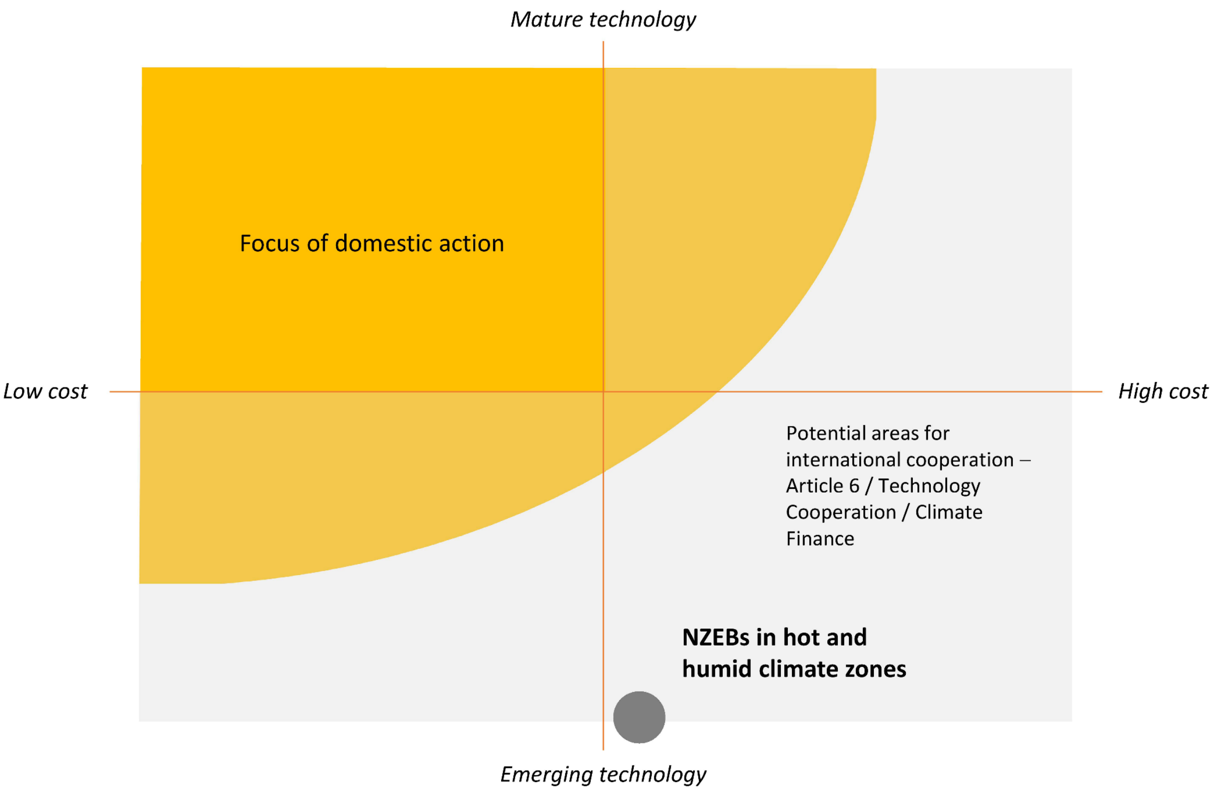

Figure 2: Inaccessibility for NZEBs in hot and humid climate zones

4.7 Ex ante estimation of emission reductions

As discussed above, estimations vary both with regard to estimations of current energy consumption of residential housing as well as future trends in the sector. Other policies including building codes, energy performance standards for appliances, renewable policies that will affect the grid emission factor, and possible future reforms of the energy subsidy system, can also not be predicted with certainty but may have important implications for baseline determination.

Considering the pilot is expected to eliminate use of electricity from the grid on a net basis, the rough estimate of the emission reductions is the same as the baseline or 58,033,685 g (at 220 gCO_2 per kWh) per year for the 48-unit building in the case study.

This does not include either the energy efficiency measures currently required by the Colombian Sustainable Construction Guide, which is currently facing implementation challenges, or future relevant policy measures other than that the grid may become cleaner.

4.8 Data parameters and monitoring plan

Estimates of emission reductions are based on bottom up calculations for energy consumption, and current grid emission factors. Once the baseline has been determined according to the process above, monitoring the project is fairly simple in that it would consist of electricity and gas meter readings for buildings in the sample used to assess the baseline, as well as electricity meter readings from the project buildings to verify that the building actually produces as much electricity as it consumes on a net basis. Gas appliances would be eliminated in the project buildings, which also eliminates the need for a gas connection and any meter readings. Any surplus electricity consumed from the grid could be accounted for but is not expected.

Because of Colombia's large dependence on hydroelectricity, and changing weather patterns, the grid emission factor of Colombia is highly variable. Large wind and solar expansion plans are expected to have a significant impact on the grid emission factor over the crediting period, and even more so if current hydro capacity is used as storage instead of base load source. The grid emission factor is therefore an important data parameter that cannot accurately be determined ex ante and would require yearly adjustments to represent an accurate and robust estimate of reduced emissions from electricity generation.

5 Start date, crediting period type and duration, host country benefit, OMGE, and ITMOs

An Article 6 pilot to support NZEBs in Colombia could include a few demonstration projects. Further project proponents interested in participating could have a window of opportunity to participate in the pilot, limited to an initial five-year term (e.g. until 2024/2025) coinciding with the NDC cycle, to be reviewed and updated with a revised baseline benchmark for the period 2025-2030. For instance, for future buildings / continuation of the programme, after every five years the host country and project partners should review: a) how much the sectoral situation has changed i.e. if the benchmark is still relevant; and b) whether they are still eligible to get the extent of support they are receiving, as increased adoption over time will remove the market barriers and shift current practice closer to NZEB.

Although Parties were not able to agree on rules for Article 6 at the 2018 COP24 in Katowice, project activities to promote NZEBs in Colombia could conceivably start already in 2019. If first installations were to be completed by 2020, a ten-year crediting period corresponding to the Colombian NDC would cover the period during which NZEBs would not yet have paid for themselves. Emission reductions from the buildings will continue as long as they are inhabited, and emission reductions beyond the crediting period would represent a host country benefit. Operationalising an overall mitigation of global emissions (OMGE) would require a share of emission reductions to be cancelled (Schneider *et al.*, 2018) and several countries have called for a share of proceeds (SOP) from Article 6.2 transfers to also raise funds for adaptation (Grimm *et al.*, 2018). We propose a share of emission reductions be cancelled for overall mitigation, at least percentage determined as the negotiated outcome from SBSTA negotiating the Paris Rulebook. Omitting OMGE and SOP would create an uneven playing field in global carbon markets between Art 6.2 and Art 6.4. If the pilot or an ERPA for the pilot starts implementation before the adoption of guidance for Article 6.2 and rules, modalities and procedures for 6.4, any agreement between project parties should include a clause that requires retroactive adjustments to comply with Article 6 rules for OMGE and SOP.

6 Business models for project implementation

The cooperation between the project developer and the parties can be structured around different business models. These models vary with respect to who is the project developer, the costs for each party, and the potential barriers in the specific context. We explore each model below.

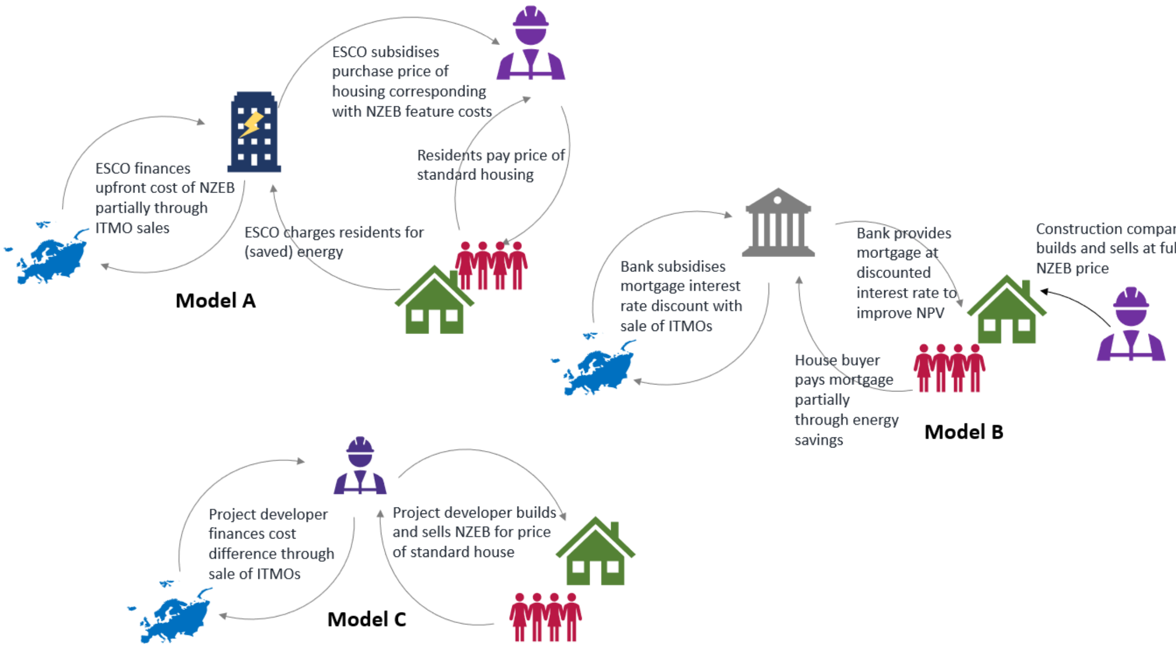

Figure 3: Potential business models

In **Model A**, a housing construction company would build NZEBs and sell them at prices close to the price of standard buildings. Residents would pay close to the standard price of housing, with the difference between a standard building and an NZEB being paid for by an Energy Service Company (ESCO). Instead of having zero energy costs, as they would have had they paid for the NZEB outright, residents would pay the ESCO a monthly energy service fee that is slightly reduced from the price that they would have paid for electricity and gas in a standard house so as to provide an incentive for residents to buy housing in the NZEB. Such an energy service fee, combined with the sale of ITMOs could provide the ESCO with a revenue stream that could be used to recoup the initial price premium over the price of a standard residential building over a number of years. Such a model would be a new build, hot and humid climate zone adaptation of the Dutch Energiesprong[11] initiative that originally targeted retrofits for social housing in the Netherlands. The Energiesprong model was however developed for rental housing and focusses primarily on reducing heating demand and would require further investigation with regard to its feasibility for buildings where housing units are owned by residents that have high cooling costs. CO_2 emission reduction prices on a per tonne basis would be closely related to interest rates that the ESCO could get from local financial institutions but could also be financed through soft loans. Initially, as the ESCO business model is also still quite novel in Colombia,

[11] More information on Energiesprong can be found at: https://energiesprong.org/about/

significant international support may be needed initially, but could be reduced in time. This model is likely to be most feasible.

In **Model B**, banks could use the sale of ITMOs to subsidise interest rates for mortgages of energy efficient housing units. House buyers would pay the full price of an NZEB building but would have no energy costs thereafter. The level of subsidy would be dependent on what is necessary to increase the NPV of the investment to the housing resident and would depend on the strata. Such a model is more likely to work for higher income groups in higher strata that have the ability to take on more debt to finance the extra cost of the NZEB features and who pay a premium on their energy bills. This could extend the current existing programmes of Bancolombia and Davividenda to NZEB buildings, but would require a concerted effort to build and certify NZEBs and educate potential buyers, which is currently beyond the scope of the Bancolombia and Davivienda programme efforts. The Colombian government may not share interest in reducing the energy consumption of these socio-economic groups as the price premium that they pay to subsidise lower strata would create a larger deficit that the Colombian government would have to make up for out of tax revenue.

In **Model C**, a project developer could build and sell NZEBs for a standard price competitive with other residential housing. The cost difference could be covered through the sale of ITMOs. Based on our case study however, such a model would imply very high emission reduction costs per tonne – depending on the baseline and using a grid emission factor of 220 gCO_2 per kWh, annual emission reductions would likely be less than 580 tCO_2. If a crediting period lasts ten years, and using the overall cost estimations from our case study, costs would be above $626.21 USD per tonne CO_2 reduced. This limits the feasibility of such a model being competitive in international carbon markets. Potential price impacts from a share of proceeds for adaptation and for an overall mitigation of GHG are not taken into account here; however, Schneider et al. (2018) have explored the potential impacts of various shares of OMGE on prices.

7 Environmental impact assessment and sustainable development goals co-benefits

As a conceptual virtual pilot study, we have not carried out an Environmental Impact Assessment (EIA), although an NZEB is expected to be generally comparable to a standard building and would need to comply with local planning and zoning laws. An EIA for a virtual pilot would provide project developers and the Governments of Colombia and Sweden with information of possible environmental effects of the project, including transboundary impacts.

Article 6 provides that the international transfer of emissions, and other cooperative actions, should promote sustainable development. The construction of NZEBs would contribute to a number of SDGs in particular, highly efficient buildings using decentralised solar PV in urban contexts will have positive linkages towards SDG 1 (No poverty), SDG 3 (Good health and well-being), SDG 7 (Affordable and clean energy), SDG 8 (Decent work and economic growth), SDG 11 (Sustainable cities and communities), and SDG 12 (Responsible consumption and production). Table 12 explores how the pilot project contributes to the realization of these SDGs.

Table 12: Contribution of the pilot project to sustainable development goals.

SD Goal	SDG target	Description of link with mitigation action and nature (green = potential synergy, orange = potential trade-off)	
1. No poverty	1.2, 1.4	• Reductions in costs increase dispensable income and savings; • Increases access to new technologies.	green
3. Good health and well-being	3.4, 3.9	• Improves air quality, internal temperatures and mental health as well as well-being; • A passive house compliant building increases indoor air quality.	green
7. Affordable and clean energy	7.1, 7.3	• Decreases energy poverty due to improved energy affordability; • Improves access to modern and sustainable energy services; • Increases energy efficiency.	green
8. Decent work and economic growth	8.1, 8.2, 8.4, 8.5	• Building energy efficiency and RE integration activities contribute to technological and infrastructure upgrading, and supports economic diversification and innovation in the country; • These interventions could contribute to sustained economic growth, through job creation, and establishment of new industrial activity; • These interventions further increase resource efficiency and contribute to decoupling growth from environmental degradation; • Deployment of new energy technologies can support economic productivity by creating new industrial activity, supply chain development, and innovation.	green
11. Sustainable cities and communities	8.3	• Supports decent job creation and entrepreneurship.	green
	11.3, 11.4, 11.6	• Contributes to sustainable urbanisation; • Reduces impact of cities through more efficient energy use and reduced pollution from energy consumption; • Deploying solar PV contributes to reducing the environmental impact of cities by reducing the amount of GHG and air pollutants from power generation.	green
	11.1	• Reduces access to affordable housing (more expensive once fitted with RE technologies).	red
12. Responsible consumption and production	12.2, 12.4	• Increases resource efficiency through more energy efficient buildings and appliances; • Contributes to reduced air pollution through reduced fuel consumption.	green

8 Colombian readiness for Article 6 engagement

In terms of readiness for engagement in Article 6, Colombia has significant experience to draw and build on. Colombia is host for a number of CDM projects and ranks 12th globally in the number of registered projects. In 2016, Colombia introduced a carbon tax of approximately 5 USD per tonne which is applied to liquid fossil fuels and industrial natural gas users. Compliance entities can reduce their tax burden through purchasing and cancelling eligible offsets from a number of standards including the CDM. This has helped project developers in Colombia that are able to supply reductions for under 5 USD per tonne CO_2 but has limited potential for more expensive mitigation options.

Colombia submitted its economy-wide NDC to the UNFCCC in September 2015 and ratified the Paris Agreement on 12 July 2018. National Communications were submitted in 2001, 2010 and 2017. Four national GHG inventories were conducted between 1990 and 2014. Preparations are currently underway for a revision of the NDC.

The "Paris Rulebook" COP24 decision (CP24 para 77 d) calls for Parties participating in cooperative approaches that involve the use of ITMO's (here understood to be potentially both cooperative approaches under Article 6.2 and Article 6.4) to provide:

(i) *The annual level of anthropogenic emissions by sources and removals by sinks covered by the NDC on an annual basis reported biennially;*

(ii) *An emissions balance reflecting the level of anthropogenic emissions by sources and removals by sinks covered by its NDC adjusted on the basis of corresponding adjustments undertaken by effecting an addition for internationally transferred mitigation outcomes first-transferred/transferred and a subtraction for internationally transferred mitigation outcomes used/acquired, consistent with decisions adopted by the CMA on Article 6; must provide the "annual level of anthropogenic emissions by sources and removals by sinks covered by the NDC on an annual basis reported biennially";*

(iii) *Any other information consistent with decisions adopted by the CMA on reporting under Article 6;*

(iv) *Information on how each cooperative approach promotes sustainable development; and ensures environmental integrity and transparency, including in governance; and applies robust accounting to ensure inter alia the avoidance of double counting, consistent with decisions adopted by the CMA on Article 6.*

As negotiations are ongoing, in the absence of further guidance or rules modalities and procedures adopted by the CMA, the reporting requirements of the Paris Rulebook already represent a challenge for Colombia, requiring increased institutional capacity and resources to conduct annual GHG inventories.

Colombia is working on the further development of the national registry of emission reduction (RENARE), which could be used to track Article 6 transfers and corresponding adjustments. Legislation has also been passed that could be used for a legal mandate to develop an emissions trading system which could also incorporate such a tracking function as part of its registry. It is assumed that the current DNA would continue to retain authority to issue host country letters of approval, but this mandate would need expanding to carry out corresponding adjustments with important implications for NDC achievement.

8.1 Complementary Article 6.8 non-market-based approaches

Article 6 of the Paris Agreement also recognises and provides a framework for non-market approaches that do not involve the transfer of mitigation outcomes. While avoiding duplication, it has been proposed that such a framework could lend itself to initiatives such as fossil fuel subsidy reform, which Colombia could take advantage of to amend its electricity and gas pricing structures. Such cooperation is not only economic but would have to take political-economy and poverty considerations into account. Various more efficient options exist (McRae and Wolak, 2019). Other options include academic exchange programmes and scholarships for Colombian architects and architecture students to learn about and collaboratively design NZEB buildings. Technical training and exchanges between officials or certified third-party verifiers for building codes – "curadores" in Colombia, and countries that have particularly successfully implemented ex-post building code compliance and energy use audits could also help strengthen implementation of Colombia's domestic energy efficient building implementation efforts.

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