The impact of sustainable buildings in electricity demand in Colombia: a system dynamics approach

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Extended abstract:

One of the greatest challenges of Colombia in the XXI century is the energy transition towards a more sustainable energy supply and more efficient consumption. Consistent with the SDGs, the country has established different goals that involve the construction sector, such as the increase in energy efficiency in buildings not only from its direct use but also from its design. The Mining and Energy Planning Unit (UPME from its acronym in Spanish) estimates that the construction sector along with residential and commercial buildings accounts for 23% of the country's energy consumption (UPME, 2016), most of this in the form of electricity. Thus, the Colombian Ministry of Housing, Cities, and Territory (Minvivienda, from its acronym in Spanish) launched in 2015 an SB standard that establishes the parameters that should be met in terms of energy and water in any new building constructed after 2015. Old buildings are not required to achieve the SB standards, but the owners can voluntarily adapt the buildings and apply for energy efficiency (EE) incentives (UPME, 2020, 2018). Owners can also obtain a certification from the Colombian Sustainable Buildings Council (CCCS by its acronym in Spanish), such as LEED or "CASA Colombia."

Although the SB standard is mandatory, a recent study found that its adoption of it is still low. In Bogota, the country's capital, the compliance of the SB standards is high (around 70% of new buildings meet the parameters), but the rest of the country tells a different story. In cities like Cali and Barranquilla, many of the construction sector agents ignored the existence of the law (CONPES and DNP, 2018). Additionally, many of the local control entities lack monitoring and law enforcement capacity; thus, some agents are aware of the SB standard but have decided not to comply with it because nobody is checking.

The UPME estimates that there is an energy savings potential between 10 – 40% depending on the type of building and the climate of each city, that could be reached if the informality rate in the construction sector decreases, and SB and EE practices are implemented (Minvivienda, 2015a; UPME, 2016). However, it is still unclear how and when such potential savings could be reached. Since the SB standard applies only to new buildings constructed after 2015, the potential savings may not be as large as expected. It is essential to consider the effect of the accumulated old buildings that cannot be demolished. In this study, we developed a system dynamics model to evaluate different scenarios of sustainable construction in the four

main cities in Colombia: Bogota, Medellin, Cali, and Barranquilla. We considered three main state variables, as shown in Figure 1: sustainable buildings (that meet the SB standard), efficient buildings (old buildings that adopt EE measures), and traditional buildings.

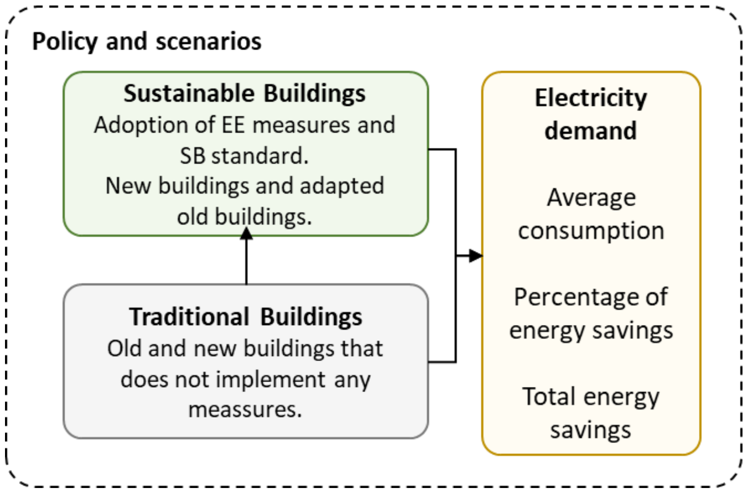

Figure 1 – Blocks diagram for the developed model.

We evaluated four scenarios that depend on an exogenous driver of the construction sector (fossil fuel prices) and the favorability of national policy towards energy transition, as shown in Figure 2. These scenarios are called: Jenga (low fossil fuel prices and unfavorable policies), Monopoly (high fossil fuel prices and unfavorable policies), Snakes and Ladders (low fossil fuel prices and favorable policies) and Chess (high fossil fuel prices and favorable policies). We found that the maximum energy savings potential is around 12% in the biggest cities, compared to no SB and no EE scenario. This potential can be reached when all the new buildings meet the SB standards, and all the old ones are adapted to be more efficient. Under the best scenario, Bogota may reach this potential by 2025, Medellin by 2030, while Cali and Barranquilla will not reach it before 2035. We also considered a rebound effect, in which 30% of the savings are compensated with a larger consumption. In this case, the maximum potential would be around 7%.

We conclude that policymakers should focus on guaranteeing the compliance of the SB standard in new buildings, especially in Cali and Barranquilla. Additionally, to the SB standard, and perhaps of more urgency in Bogota and Medellin, there is a need for improving EE programs in old buildings; these two cities have a small available area for construction, thus, old buildings will remain as the major contributors to the energy consumption. Finally, we remark that future work should include other dimensions of sustainable construction, such as water consumption and waste management. Additionally, an endogenous modelling of the construction cycles in Colombia can be included to improve the understanding of such effects in the sustainability of buildings.

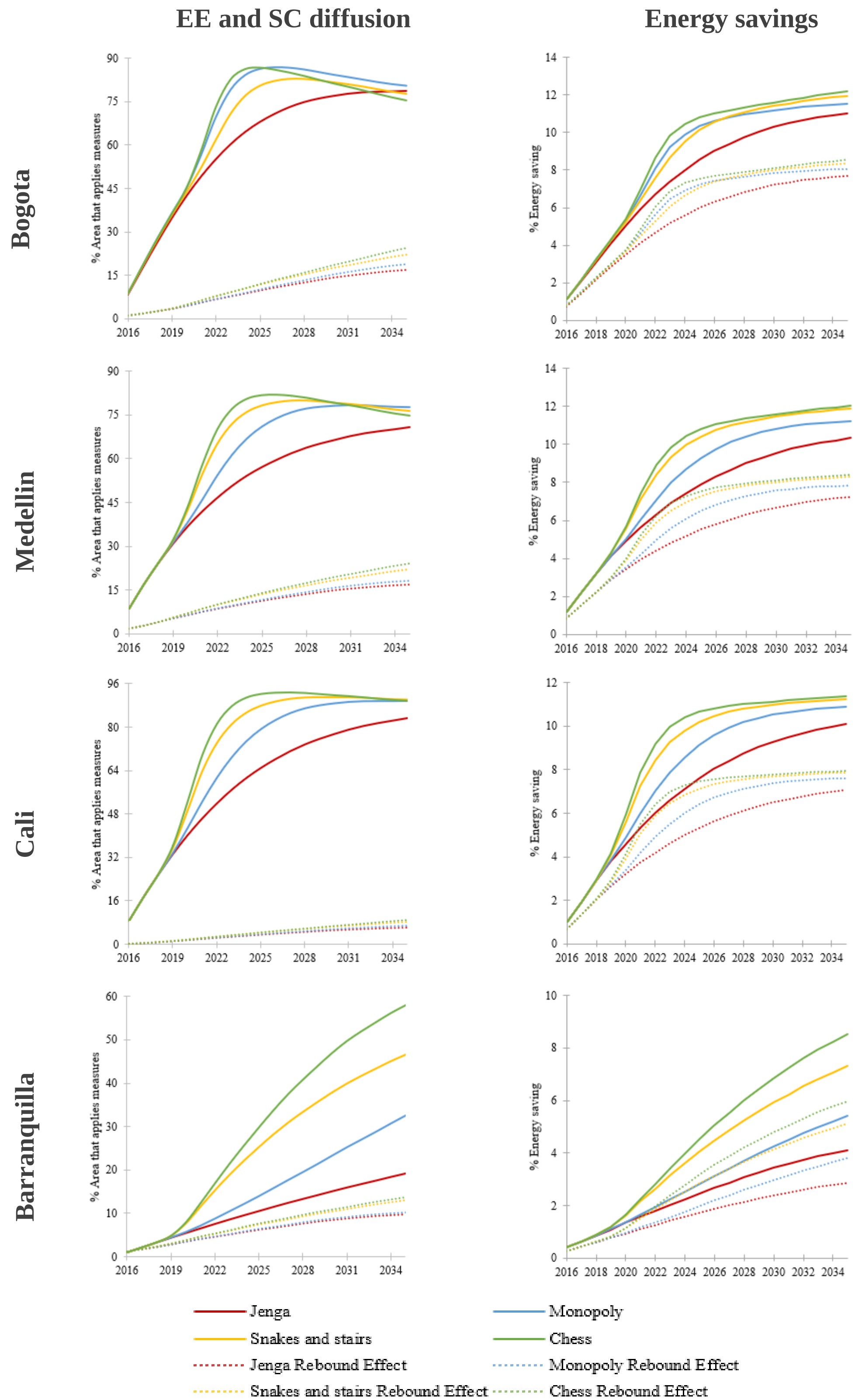

Figure 2 – diffusion of sustainable buildings and potential energy savings under different scenarios.

References:

Abu Bakar, N.N., Hassan, M.Y., Abdullah, H., Rahman, H.A., Abdullah, M.P., Hussin, F., Bandi, M., 2015. Energy efficiency index as an indicator for measuring building energy performance: A review. Renew. Sustain. Energy Rev. 44, 1–11. https://doi.org/https://doi.org/10.1016/j.rser.2014.12.018

Arias-Gaviria, J., Larsen, E.R., Arango-Aramburo, S., 2018. Understanding the future of Seawater Air Conditioning in the Caribbean: A simulation approach. Util. Policy 53, 73–83. https://doi.org/10.1016/J.JUP.2018.06.008

Asere, L., Mols, T., Blumberga, A., 2016. Assessment of Indoor Air Quality in Renovated Buildings of Liepāja Municipality. Energy Procedia 91, 907–915. https://doi.org/https://doi.org/10.1016/j.egypro.2016.06.257

Barlas, Y., 1996. Formal aspects of model validity and validation in system dynamics. Syst. Dyn. Rev. 12, 183–210. https://doi.org/10.1002/(SICI)1099-1727(199623)12:3<183::AID-SDR103>3.0.CO;2-4

Bass, F., 2004. Comments on "A New Product Growth for Model Consumer Durables": The Bass Model. Manage. Sci. 50, 1833–1840. https://doi.org/10.1287/mnsc.1040.0300

Bass, F., 1969. A new product growth model for product diffusion. Manage. Sci. 15, 215–227.

Brandon, P.S., Lombardi, P., 2010. Evaluating sustainable development in the built environment. John Wiley & Sons.

Brännlund, R., Ghalwash, T., Nordström, J., 2007. Increased energy efficiency and the rebound effect: Effects on consumption and emissions. Energy Econ. 29, 1–17.

Chan, W.W., 2005. Predicting and saving the consumption of electricity in sub-tropical hotels. Int. J. Contemp. Hosp. Manag. 17, 228–237. https://doi.org/10.1108/09596110510591918

Chang, C.C., Shi, W., Mehta, P., Dauwels, J., 2019. Life cycle energy assessment of university buildings in tropical climate. J. Clean. Prod. 239. https://doi.org/10.1016/j.jclepro.2019.117930

Chen, Y., Tan, H., Wu, J., Song, X., 2017. Resilient regional energy benchmarking of classified public buildings. Energy Procedia 142, 2365–2370. https://doi.org/https://doi.org/10.1016/j.egypro.2017.12.168

CONPES, DNP, 2018. Documento CONPES 3919- Política Nacional de Edificaciones Sostenibles.

Damiens, J., Li, M., Pei, Z., Liu, Y., Zhu, Y., 2014. Using natural ventilation in office buildings under subtropical climate: A case Study in Shenzhen. Lect. Notes Electr. Eng. https://doi.org/10.1007/978-3-642-39584-0_43

DANE, 2019a. Boletín técnico: Indicador de Inversión en Obras Civiles (IIOC) I trimestre de 2019. Bogotá D.C.

DANE, 2019b. Anexo Series Censo de Edificaciones II trimestre de 2019.

DANE, 2019c. Series Censo de Edificaciones II trimestre de 2019.

Deb, C., Lee, S.E., 2018. Determining key variables influencing energy consumption in office buildings through cluster analysis of pre- and post-retrofit building data. Energy Build. 159, 228–245. https://doi.org/https://doi.org/10.1016/j.enbuild.2017.11.007

Deng, S.-M., Burnett, J., 2000. A study of energy performance of hotel buildings in Hong Kong. Energy Build. 31, 7–12.

Garg, A., Maheshwari, J., Shukla, P.R., Rawal, R., 2017. Energy appliance transformation in commercial buildings in India under alternate policy scenarios. Energy 140, 952–965. https://doi.org/https://doi.org/10.1016/j.energy.2017.09.004

Gillingham, K., Rapson, D., Wagner, G., 2016. The rebound effect and energy efficiency policy. Rev. Environ. Econ. Policy 10, 68–88.

Gómez Gómez-Plana, A., Arocena Garro, P., Peña Vidondo, S., 2016. La eficiencia energética, el efecto rebote y el crecimiento económico. Papeles Energía, número 2, diciembre 2016.

Greening, L.A., Greene, D.L., Difiglio, C., 2000. Energy efficiency and consumption—the rebound effect—a survey. Energy Policy 28, 389–401.

John, G., Clements-Croome, D., Jeronimidis, G., 2005. Sustainable building solutions: a review of lessons from the natural world. Build. Environ. 40, 319–328. https://doi.org/https://doi.org/10.1016/j.buildenv.2004.05.011

Khoshbakht, M., Gou, Z., Dupre, K., 2018. Energy use characteristics and benchmarking for higher education buildings. Energy Build. 164, 61–76. https://doi.org/https://doi.org/10.1016/j.enbuild.2018.01.001

Lee, S.E., Rajagopalan, P., 2008. Building energy efficiency labeling programme in Singapore. Energy Policy 36, 3982–3992. https://doi.org/https://doi.org/10.1016/j.enpol.2008.07.014

Lenoir, A., Thellier, F., Garde, F., 2011. Towards net zero energy buildings in hot climate, part 2: Experimental feedback, in: ASHRAE Transactions. pp. 458–465.

Leong, S.M., Ibrahim, H., 2007. Sustainable green buildings - The Malaysian effort, in: Proceedings - 9th Asia Pacific Conference on the Built Environment 2007: "Sustainable HVAC and R Technology."

Ma, H., Lai, J., Li, C., Yang, F., Li, Z., 2019. Analysis of school building energy consumption in Tianjin, China. Energy Procedia 158, 3476–3481. https://doi.org/https://doi.org/10.1016/j.egypro.2019.01.924

Massiani, J., Gohs, A., 2015. The choice of Bass model coefficients to forecast diffusion for innovative products: An

empirical investigation for new automotive technologies. Res. Transp. Econ. 50, 17–28.
Minvivienda, 2015a. Resolucion Nro 549 de 2015. Minist. Vivienda Ciudad y Territ.
Minvivienda, 2015b. Anexo Técnico Resolución 549 de 2015.
Moghimi, S., Azizpour, F., Mat, S., Lim, C.H., Salleh, E., Sopian, K., 2014. Building energy index and end-use energy analysis in large-scale hospitals—case study in Malaysia. Energy Effic. 7, 243–256.
Moghimi, S., Mat, S., Lim, C.H., Zaharim, A., Sopian, K., 2011. Building energy index (BEI) in large scale hospital: Case study of Malaysia, in: Recent Researches in Geography, Geology, Energy, Environment and Biomedicine - Proc. of the 4th WSEAS Int. Conf. on EMESEG'11, 2nd Int. Conf. on WORLD-GEO'11, 5th Int. Conf. on EDEB'11. pp. 167–170.
Nässén, J., Holmberg, J., 2009. Quantifying the rebound effects of energy efficiency improvements and energy conserving behaviour in Sweden. Energy Effic. 2, 221–231.
Paramita, B., Rabbani, B.A., Sari, D.C.P., 2019. Energy optimization on preliminary design of the botani museum using sefaira®. Int. J. Eng. Adv. Technol. 8, 2614–2618.
Perilla, J.R., 2010. El impacto de los precios del petróleo sobre el crecimiento económico de Colombia. Rev. Econ. del Rosario 13, 75–116.
Petrullo, M., Jones, S.A., Morton, B., Lorenz, A., 2018. World green building trends 2018–Smart market report. Dodge Data Anal.
Qu, Y., Zhang, Z., Wang, H., Yang, F., 2017. Energy Consumption Analysis of Public Buildings Located in the Severe Cold Region. Procedia Eng. 205, 2111–2117. https://doi.org/https://doi.org/10.1016/j.proeng.2017.10.133
Rao, K.U., Kishore, V.V.N., 2010. A review of technology diffusion models with special reference to renewable energy technologies. Renew. Sustain. Energy Rev. 14, 1070–1078. https://doi.org/10.1016/j.rser.2009.11.007
Secretaría Distrital de Planeación, B.D.C., 2019. Protocolo de implementación para el cumplimiento de los porcentajes de ahorro en agua y energía para la ciudad de Bogotá D. C., establecidos en la Resolución 549 de 2015 del Ministerio de Vivienda, Ciudad y Territorio.
SUI, 2019. Reportes Energia/Comercial/Consolidado Energía por Empresa Departamento y Municipio [WWW Document]. URL http://reportes.sui.gov.co/fabricaReportes/frameSet.jsp?idreporte=ele_com_096
Tahir, M., Jamaludin, R., Nasrun, M., Mohd Nawi, M.N., Baluch, N., Mohtar, S., 2017. Building energy index (BEI): A study of government office building in Malaysian public university. J. Eng. Sci. Technol. 12, 192–201.
UNEP, 2011. Towards a green economy: Pathways to sustainable development and poverty eradication. Nairobi, Kenya UNEP.
Universidad Nacional de Colombia, 2007. Caracterización del consumo de energía final en los sectores terciario, grandes establecimientos comerciales, centros comerciales, UPME.
UPME, 2020. Incentivos Eficiencia Energética - Normatividad [WWW Document]. URL https://www1.upme.gov.co/Paginas/incentivos-EE.aspx (accessed 2.29.20).
UPME, 2018. Resolución No. 000463.
UPME, 2016. Plan de Acción Indicativo de Eficiencia Energética 2017-2022. Minist. Minas y Energía 1–157.
Vaisi, S., Pilla, F., McCormack, S.J., 2018. Recommending a thermal energy benchmark based on CIBSE TM46 for typical college buildings and creating monthly energy models. Energy Build. 176, 296–309. https://doi.org/https://doi.org/10.1016/j.enbuild.2018.07.041
Wei, T., Liu, Y., 2017. Estimation of global rebound effect caused by energy efficiency improvement. Energy Econ. 66, 27–34. https://doi.org/https://doi.org/10.1016/j.eneco.2017.05.030
Xin, Y., Lu, S., Zhu, N., Wu, W., 2012. Energy consumption quota of four and five star luxury hotel buildings in Hainan province, China. Energy Build. 45, 250–256. https://doi.org/https://doi.org/10.1016/j.enbuild.2011.11.014
Yılmaz, M., Bakış, A., 2015. Sustainability in Construction Sector. Procedia - Soc. Behav. Sci. 195, 2253–2262. https://doi.org/https://doi.org/10.1016/j.sbspro.2015.06.312
Yu, C., Pan, W., Zhao, Y., Li, Y., 2015. Challenges for Modeling Energy Use in High-rise Office Buildings in Hong Kong. Procedia Eng. 121, 513–520. https://doi.org/https://doi.org/10.1016/j.proeng.2015.08.1100