

LETTER • OPEN ACCESS

Implementing nationally determined contributions: building energy policies in India's mitigation strategy

To cite this article: Sha Yu *et al* 2018 *Environ. Res. Lett.* **13** 034034

View the [article online](#) for updates and enhancements.

You may also like

- [Trees in cool climate cities may increase atmospheric carbon by altering building energy use](#)
Tedward Erker and Philip A Townsend
- [Energy transition and technical energy regulations in the building sector](#)
C Knoeri, M Schwarz and C Nakhle
- [BIM-based real time building energy simulation and optimization in early design stage](#)
Hao Gao, Liwenbo Zhang, Christian Koch et al.

Recent citations

- [Energy demand transitions and climate mitigation in low-income urban households in India](#)
Radhika Khosla *et al*

Environmental Research Letters



LETTER

OPEN ACCESS

RECEIVED

12 October 2017

REVISED

2 February 2018

ACCEPTED FOR PUBLICATION

7 February 2018

PUBLISHED

9 March 2018

Original content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](#).

Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.



Implementing nationally determined contributions: building energy policies in India's mitigation strategy

Sha Yu^{1,3} , Meredydd Evans¹, Page Kyle¹, Linh Vu¹, Qing Tan¹, Ashu Gupta² and Pralit Patel¹

¹ Joint Global Change Research Institute, Pacific Northwest National Laboratory, 5825 University Research Court, Suite 3500, College Park, Maryland 20740 United States of America

² Design2 Occupancy Services LLP, A-75 Sitapura Industrial Area, Tonk Road, Jaipur, Rajasthan 302022 India

³ Author to whom any correspondence should be addressed.

E-mail: sha.yu@pnnl.gov

Keywords: developing countries, nationally determined contributions, integrated assessment modeling, building energy efficiency, India

Supplementary material for this article is available [online](#)

Abstract

The Nationally Determined Contributions are allowing countries to examine options for reducing emissions through a range of domestic policies. India, like many developing countries, has committed to reducing emissions through specific policies, including building energy codes. Here we assess the potential of these sectoral policies to help in achieving mitigation targets. Collectively, it is critically important to see the potential impact of such policies across developing countries in meeting national and global emission goals.

Buildings accounted for around one third of global final energy use in 2010, and building energy consumption is expected to increase as income grows in developing countries. Using the Global Change Assessment Model, this study finds that implementing a range of energy efficiency policies robustly can reduce total Indian building energy use by 22% and lower total Indian carbon dioxide emissions by 9% in 2050 compared to the business-as-usual scenario. Among various policies, energy codes for new buildings can result in the most significant savings. For all building energy policies, well-coordinated, consistent implementation is critical, which requires coordination across different departments and agencies, improving capacity of stakeholders, and developing appropriate institutions to facilitate policy implementation.

Introduction

Countries have put forward their mitigation commitments under the Nationally Determined Contributions (NDCs), which are key instruments for implementing the Paris Agreement [1]. Assessments of these pledges have focused on implications on national or global greenhouse gas (GHG) emission pathways or global temperature change [2–4]. Few efforts have been made to study how these pledges would be implemented in the real world, although the success of the Paris Agreement is contingent upon effective implementation [5]. In addition, sectoral policies may have significant impacts on emissions reductions [2, 3, 6, 7]. Understanding how sectoral policies can contribute to climate goals is critical in achieving maximum reductions.

Buildings accounted for around one third of global final energy use in 2010, and building energy consumption is expected to increase as income grows in developing countries [7, 8]. India, like most developing countries, is experiencing rapid growth in gross domestic product (GDP), population, and its building stock. As Indians get wealthier, they are better able to afford larger homes, higher living standards, and more modern amenities. Businesses are also expanding. Presently, India's buildings consume over one third of the country's electricity, and, because of these underlying trends, India is facing substantial increases in energy demand, particularly for electricity. Electricity consumption in Indian buildings increased at 8% annually during 2000–2013, among the highest in major economies. In 2013 buildings accounted for 41% of total final energy use and 38% of electricity demand in India [9, 10].

As with many developing country signatories to the Paris Agreement, the Indian government recognizes both the benefits of growth and the challenges that come with it. The government launched several major policy initiatives to improve energy efficiency and reduce GHG emissions, including those from the buildings sector (see supplementary information (SI) section S1 available at stacks.iop.org/ERL/13/034034/mmedia for detailed policies). India's NDC also lists several building energy efficiency policies as part of the country's mitigation strategies.

Energy conservation and efficiency improvements in the built environment have substantial potential to reduce GHG emissions and mitigate climate change [6, 7, 11]. However, existing assessments of countries' NDCs primarily examined implications for the energy supply system. In addition, these studies typically used a hypothetical carbon price to assess mitigation potential, while in the real world, countries generally use policies beyond the carbon price for climate change mitigation [3, 12]. Studies have also shown that sectoral policies would have significant impacts on buildings whereas carbon pricing would only slightly affect building energy use and emissions [13–15]. Bottom-up buildings sector studies, on the other hand, looked at specific sectoral policies but they typically failed to provide a complete assessment of how these policies affect future building energy use or to consider the interactions between buildings and the energy system [8, 13, 16–21]. There has hitherto been no comprehensive effort to assess the impacts of building energy policies and their contributions to a country's mitigation strategies. This study fills this gap, importantly addressing the issue of real-world policy development and implementation. As such, it can provide helpful insights to a wide range of developing countries seeking to understand their options.

Here we analyze long-term impacts of a suite of building energy policies on urban residential, rural residential, and commercial buildings, while factoring in India-specific policy options and constraints. To reflect India's circumstances, we do not assess the most aggressive building energy policies, but rather enhanced ambition from India's pledges under the Paris Agreement. We aim to answer two key questions faced by policy makers. First, how would the Indian buildings sector evolve in the near and long terms, induced by possible changes in population, income, urbanization, and climate? Second, how might building energy policies, singularly or in combination, alter the evolution of the buildings sector and thus reduce energy consumption and attendant carbon emissions? What does this tell us about the importance of sectoral policies in a large developing country? To address these questions, we use an integrated assessment model—the Global Change Assessment Model (GCAM) [22]—to capture the dynamics between building energy policies, socioeconomic development, and technological changes over a long-term time horizon. In the next two sections,

we describe methodology and scenario development. Results and policy implications are discussed in the last two sections.

Data and method

Global Change Assessment Model-India (GCAM-India)

This study uses GCAM with an embedded detailed India building energy model (model version: GCAM-India) [13, 23, 24]. GCAM is a global integrated assessment model that links energy, economic, land use, and climate systems⁴. To make realistic policy analysis, we made several India-specific improvements to the core GCAM. The building energy model in GCAM-India accounts for major drivers that affect the evolution of the buildings sector, including: (1) changes in GDP, population, and urbanization; (2) floorspace expansion; (3) growth in energy service demand; and (4) choice among technologies and fuels for individual energy services. Energy demand is driven by building energy services. Demand for building energy services are affected by GDP, price, and other factors such as energy efficiency measures and climate (see SI section S2 for details on GCAM-India).

Data and assumptions

Base-year building energy consumption data for India are from energy balances and statistics of the International Energy Agency [25]. The costs and efficiency of building technologies in GCAM-India are derived from the GCAM core model with India-specific adjustments (SI section S2).

India is experiencing rapid population expansion. From 1990–2010, India's population increased by 40%, from 0.87 billion to 1.2 billion. Meanwhile, people are moving from rural areas to urban areas; the urbanization rate reached 32% in 2014. The trend of urbanization is expected to continue in the next few decades [26, 27].

India is among the fastest growing economies in the world and the average GDP growth rate from 1980–2014 is about 6.23%; however, per capita GDP in India is still very low, not unlike that in the majority of non-OECD countries in Asia and Africa. According to the International Monetary Fund, India's per capita GDP (nominal) in 2015 is \$1688 (monetary values are in 2010 US dollars; same below), only 3% of that of the United States and 20% of China's per capita GDP [28].

Future population and GDP assumptions are based on the 'middle-of-the-road' shared socioeconomic pathway (SSP2) used by the integrated assessment modeling community for Intergovernmental Panel on

⁴ GCAM is an open-source model. The model can be downloaded at: www.globalchange.umd.edu/models/gcam/. The full documentation of the model is available at: <http://jgcri.github.io/gcam-doc/toc.html>.

Table 1. Description of policy scenarios.

Policy type	Scenario name	Description
Business as usual	BAU	Development of status-quo without building energy efficiency policies
Building energy codes	Codes High	Building energy codes for urban residential, rural residential, and commercial buildings, with high compliance levels
	Codes Low	Building energy codes for urban residential, rural residential, and commercial buildings, with low compliance levels
Energy efficiency retrofit programs	Retrofits High	In addition to high compliance with codes, retrofitting 5% of existing buildings annually to code-compliant levels in urban residential, rural residential, and commercial sectors
	Retrofits Low	In addition to low compliance with codes, retrofitting 1% of existing buildings annually to code-compliant levels in urban residential, rural residential, and commercial sectors
Appliance standards and labels	Appliance MEPS	Mandatory minimum energy performance standards for air conditioners, ceiling fans, refrigerators, and televisions
	Appliance Labels	Voluntary energy labels for air conditioners, ceiling fans, refrigerators, and televisions
Subsidies for renewable energy	Solar Water Heaters	Subsidies to reduce installation costs of solar water heaters
Comprehensive building energy policies	All Efficiency Policies	Building energy codes for urban residential, rural residential, and commercial buildings, with high compliance rate; energy efficiency retrofits in 5% of existing buildings; and appliance standards for air conditioners, ceiling fans, refrigerators, and televisions

Climate Change (IPCC) assessments [29, 30]. Population and GDP assumptions are shown in SI table S1.

Building floorspace is an important driver of building energy use because end-use services such as lighting and space cooling are closely related to the size of the building. Historical data of residential floorspace are derived from survey data collected by the National Sample Survey Organization, and historical floorspace of commercial buildings is based on the estimates from the US-India Bilateral Energy Conservation and Commercialization Project Phase III [31, 32].

Future building floorspace growth in GCAM is driven by income growth and constrained by the saturation level. Total Indian floorspace is expected to increase by four times between 2010 and 2050, reaching 40 billion m² in 2050. The commercial sector has the strongest growth rate, from 0.66 billion m² in 2010 to 5.2 billion m² in 2050, with around seven-time growth. Floorspace in urban residential buildings would increase by more than six times.

Building energy policies and scenarios

Four types of policies are examined in this paper in addition to a business-as-usual (BAU) scenario: building energy codes, energy efficiency retrofits, appliance standards and labels, and incentives for renewable energy deployment. For building energy codes and energy efficiency retrofits scenarios, we also assess how low and high compliance rates affect energy savings and emissions reductions in buildings.

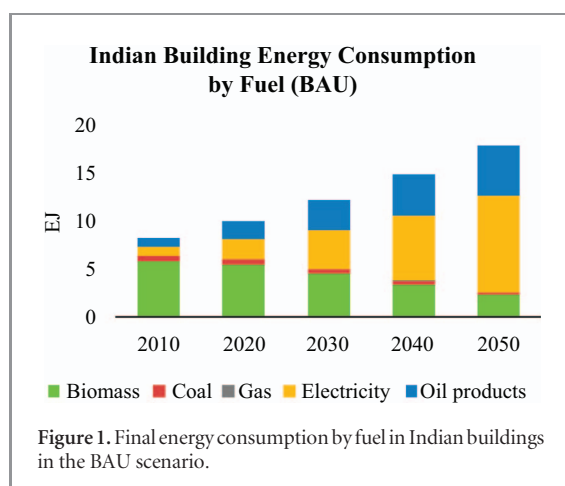
In the BAU scenario, the buildings sector evolves as it would without any additional building energy policies. The building energy code and retrofit scenarios

assume a comprehensive set of measures affecting the efficiency of the building envelope, lighting, air conditioning, and other long-lasting systems, while the appliance scenarios look at specific appliance technologies. The renewable energy scenario looks at the impact of subsidies on the deployment of solar hot water heaters. Finally, we look at a policy scenario that combines multiple energy efficiency policies. These policies affect different end-use services. Building energy codes and retrofits influence space heating/cooling and lighting, whereas appliance standards and labels affect energy use in appliances and cooling (i.e. air conditioning). Comprehensive building energy policies have impacts on space heating/cooling, lighting, and appliances. Table 1 summarizes these scenarios and assumptions and the supplementary information section S3 provides additional methodological and contextual details, as well as quantitative assumptions of these scenarios.

Results and discussion

In this section, we look at the growth trends, the impacts of sectoral policy, and then compare this with other studies that have analyzed economy-wide policies like a carbon price. Understanding the underlying growth trends is critical for developing countries as they plan future emission targets and actions. Without a robust understanding of potential growth paths, developing countries like India may be concerned about the risk of taking on deep targets. Thus, understanding growth is a critical component to setting realistic but still robust targets. It is also essential to tracking progress over time.

The impacts of sectoral policies show how each of our policy scenarios plays out in terms of emissions

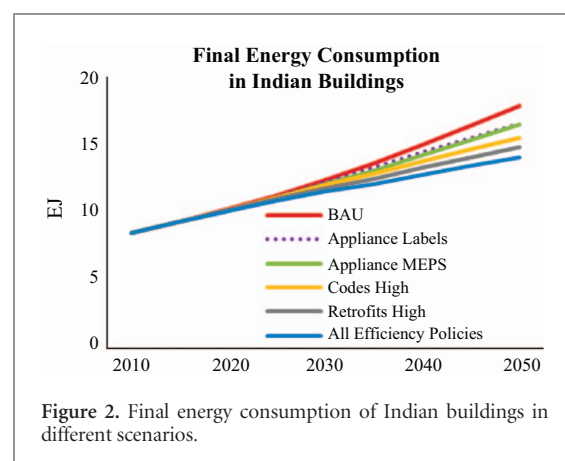


and energy use. This can help in identifying the most impactful policies, the importance of implementation, and in understanding the cumulative benefits of combining policies. In comparing these sectoral policies to economy-wide carbon strategies, we can show the relative scale of mitigation that is achievable with the two different strategies. In fact, as the results demonstrate, sectoral policies in buildings can have a significant impact on reducing emissions.

Growth trends in the Indian buildings sector in the BAU scenario

In the BAU scenario, total final energy consumption in Indian buildings doubles between 2010 and 2050, reaching 18 exajoules (EJ) in 2050 (figure 1). Electricity use from buildings increases by around 11 times; buildings become the largest end-use sector consuming electricity in India, accounting for 54% of total electricity consumption. Electricity replaces traditional biomass to become the dominant fuel used in buildings because of the growth in air conditioning and appliances and switching from inefficient traditional biomass to more efficient fuels—a trend not unique to India [23, 33].

Energy use in commercial buildings shows strong growth, from 0.5 EJ in 2010 to 5.7 EJ in 2050; demand for all services increases dramatically, increasing nine- to 13-fold. Energy use in urban residential buildings increases by around three times between 2010 and 2050, driven by high growth in air conditioning and appliance use. Electricity consumption in urban residential buildings increases dramatically, from 80 terawatt-hours (TWh) in 2010 to around 1100 TWh in 2050. In 2050, appliances, HVAC systems, and lighting account for 50%, 38%, and 10% of electricity use in urban residential buildings, respectively. Energy use in rural residential buildings decreases by 12%, as inefficient biomass use drops and electricity consumption increases rapidly. Biomass energy use decreases by 60%, from 5 EJ in 2010 to 2 EJ in 2050; coal consumption also declines by around 50%. Meanwhile, electricity use increases by six times. (SI figures S1–S4)

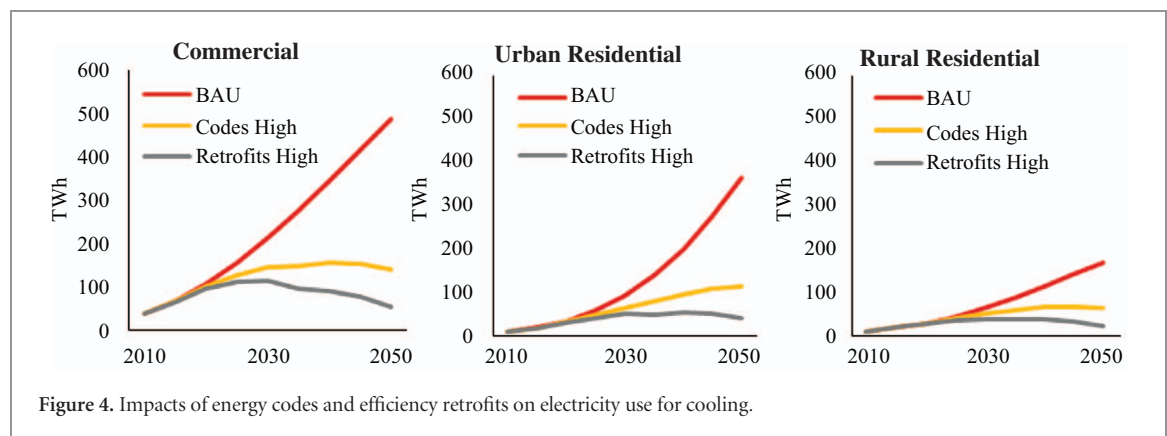
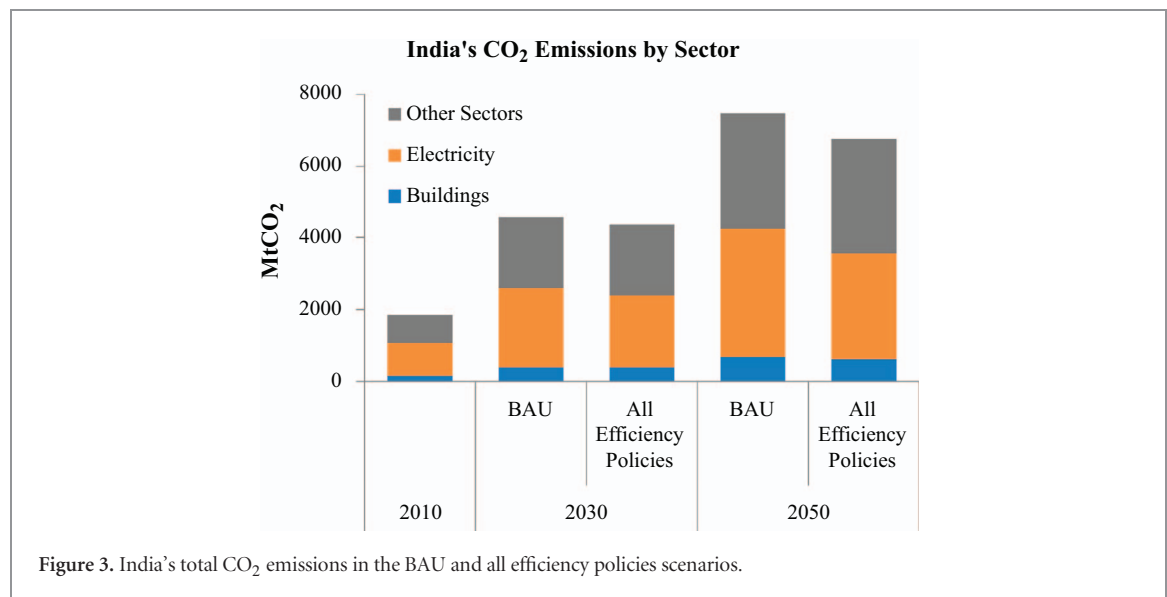


The growth in energy demand over the entire building stock would exacerbate existing stress in the power supply system and at the same time worsen air pollution by increasing combustion-related emissions and construction dust in India's cities, which are already among the most polluted in the world [34]. Importantly, climate change can further increase energy demand in Indian buildings because cooling loads would grow as temperature rises, a result that appears consistent with other studies looking at hot and tropical climates [33]. For example, temperature increases from a global BAU-level of emissions (known as the A2 emissions scenario in IPCC Assessment Reports) would lead to 15% additional cooling demand in Indian buildings compared to a scenario that does not factor in climate change (SI section S4) [35]. Thus, global climate change under this scenario would increase total Indian carbon dioxide (CO₂) emissions by 322 million metric tons (Mt) between 2015 and 2050.

Impacts of building energy policies

With rigorous building energy codes, retrofit policies, and appliance standards, total final energy consumption in buildings in 2050 could be reduced from 18 EJ in the BAU scenario to less than 14 EJ, a 22% decrease (figure 2). Electricity consumption in Indian buildings could be reduced by around 40% in 2050, from 2800 TWh–1685 TWh. These policies could reduce India's CO₂ emissions by 9% or 700 Mt. Most savings come from reduced cooling and appliance electricity consumption (figure 3) (see SI figure S5 for emissions in all scenarios). In addition to decreasing energy consumption and emissions, these building energy policies also yield other benefits, such as reducing operational costs of end users and reducing the number of power plants required.

Compared to the target in India's NDC, reducing emissions intensity per unit of GDP by 33%–35% below 2005 levels by 2030, having comprehensive building efficiency policies alone could lead to a 29% reduction in emissions intensity by 2030 and a 51% reduction by 2050 (26% reduction by 2030 and 46% reduction by 2050 in BAU). Other policies, such as



switching from fossil energy to renewables in electricity generation, can also reduce emissions, but these are beyond the scope of this paper. Emissions reductions between BAU and building energy policy scenarios in this study are only affected by changes in the buildings sector, and all other assumptions (e.g. socioeconomic growth and energy supply sectors) are held the same across all scenarios. It is also worth noting that we are not looking at net zero buildings or the most aggressive building energy policies, but rather enhanced ambition from India's pledges under the Paris Agreement. These sectoral policies are more effective in reducing energy use in Indian buildings than an economy-wide carbon tax. Chaturvedi *et al* applied a tax pathway starting at 20 USD/tC in 2020 and increasing to 360 USD/tC in 2095 and found it only reduced building final energy use by 3 EJ in 2095 [36]. The discussion below focuses on the impacts on building electricity use, as policies explored in this study mostly affect building services relying on electricity.

Building energy codes

Building energy codes can affect building energy use and associated greenhouse gas emissions for the life of the buildings. Compared to other energy efficiency

policies, energy codes with high compliance can result in the most significant energy savings.

Rigorous energy codes for new buildings (with high compliance) could reduce the average energy use intensity of Indian buildings from 0.44 GJ m⁻² to 0.38 GJ m⁻² in 2050, and have the potential to reduce India's building electricity use by 25% and cooling loads by 70% in 2050 through significant improvement in efficiencies of building envelope, HVAC, and lighting systems, compared to the BAU scenario (figure 4). This would reduce CO₂ emissions by 430 Mt and reduce coal imports by 8% in 2050. Low compliance with building energy codes, however, would double electricity use for cooling compared to the high compliance scenario (SI figure S6). The high and low compliance scenarios differ in both the level of compliance and the timing of reaching the highest compliance rate (i.e. 99% compliance by 2025 in high compliance scenarios and 80% by 2050 in low compliance scenarios). Thus, this makes it very apparent that to achieve the intended savings of building energy codes, strong, immediate enforcement is needed.

Strong code enforcement consists of code adoption, effective implementation, and robust compliance evaluation. Adoption of building energy codes in India

lies with state and local governments and often requires changing building bylaws to include energy requirements in the building permitting process. As of 2017, 11 Indian states have adopted ECBC. A survey on ECBC indicated that improving coordination among government bodies, as well as training and capacity building to raise awareness and improve technical knowledge at the state and local levels, can facilitate code adoption [37]. Once adopted, building codes are enforced by local governments, with compliance checks at the design and construction stages. Given the lack of capacity at the local level in India (as in many developing countries), using third-party inspectors is an efficient way of improving code implementation provided there are checks and balances in the third-party system. For example, the extensive use of third-party inspectors in code implementation has contributed to the rapid growth in compliance with energy codes in China. The compliance rate in Chinese urban areas has improved from 53% (design stage) and 21% (construction stage) in 2005–99.5% and 95.4%, respectively, in 2010 [38, 39]. In the long term, when building energy codes are effectively implemented, states may want to continue to monitor and evaluate code compliance to achieve the maximum benefits.

Energy efficiency retrofits

Energy efficiency retrofits are complementary to building energy codes because, while energy codes mainly target new construction, retrofit programs aim to improve efficiency of the existing building stock. In the Retrofits High scenario, energy efficiency retrofits save an additional 7% of building electricity use in 2050. Thus, robust building codes coupled with energy efficiency retrofits can save a total of 32% of future building electricity use. Also important to note is that both energy codes and retrofits can improve the welfare of the poor and promote emissions reduction and social development at the same time. Many countries, for example, have programs to retrofit low-income housing, which could help poor families avoid substantial energy costs [40, 41].

Energy efficiency retrofits in buildings are also cost effective. Studies have shown that the upfront investment in energy efficiency upgrades can be paid back over time by savings on energy costs [42]. The savings and payback periods from energy efficiency retrofits depend on multiple factors, such as pre-existing characteristics of buildings, climate, occupancy behavior, and measures installed. For example, in an energy-efficiency retrofit project in Mumbai, costs of retrofits are around \$100 000 for a building of 1634 m²; these costs are expected to be paid back in less than 5 years, with annual savings in electricity costs of more than 25% [43]. There are also instruments used to cover the upfront costs of energy efficiency retrofits. For example, through energy performance contracting, building owners can use future savings to pay for current facility upgrades and do not need to tap into their capital

budgets to cover the upfront costs of retrofits, and this is widely used in China and the United States for energy-efficiency retrofits [44].

Appliance standards and labels

Building energy codes and energy efficiency retrofits usually do not regulate plug loads, although energy consumption from appliances is increasingly important as people become richer and own more equipment. We assess the impacts of minimum energy performance standards (MEPS) and labels for air conditioners, ceiling fans, refrigerators, and televisions on building energy use. Compared to the BAU scenario, MEPS for these appliances reduce building electricity use by 8% in 2030 and 14% in 2050, while voluntary labels reduce building electricity use by 4% in 2030 and 13% in 2050. Appliance programs primarily affect the residential sector in our analysis. Residential electricity use is reduced by 13% in 2030 and 24% in 2050 for MEPS and 7% in 2030 and 23% in 2050 for labels (table 2).

In the near term, electricity savings from standards and labels for ceiling fans and televisions are higher than savings from other appliances because ownership of ceiling fans and televisions is higher. However, as income grows, more households would buy air conditioners. In the long term air conditioner standards and labels have the greatest impact on building electricity use compared to those for other products. Compared to the BAU scenario, MEPS or appliance labels could save around 40% of electricity use for air conditioning in 2050.

Having MEPS initially focusing on air conditioners, refrigerators, and televisions could generate the most significant energy savings. In addition, the electricity savings potential in 2030 from mandatory standards is significantly greater than that from voluntary labels for air conditioners and televisions (double the savings), and refrigerators (almost four times more savings with MEPS). Given that these are also widely used appliances, the impact of MEPS could be substantial.

Subsidies for renewable energy deployment

Integrating renewable energy technologies into building design is another way to reduce the carbon footprint of buildings, as most electricity used in Indian buildings is grid-supplied from coal. Thus, we analyze the impact of subsidies on the deployment of renewable energy technologies. Subsidies can greatly increase the use of renewables in buildings, especially in the early years when technology costs are high.

Solar water heaters could be a cost-effective way for water heating in Indian households, considering India's climate. Although they usually have higher upfront costs than conventional water heating systems (see SI table S6 for information on costs of water heaters), they can save money in the long run. Even without subsidies, solar water heaters may still provide 51% of service hot water in urban residential buildings in 2035 in the BAU scenario. Although the total use of water heating

Table 2. Electricity savings potential in residential buildings from appliance programs (TWh).

	2020		2030		2040		2050	
	MEPS	Labels	MEPS	Labels	MEPS	Labels	MEPS	Labels
Air conditioners	0.01	0.01	20.62	7.87	80.62	63.59	188.35	197.81
Refrigerators	1.91	0.40	35.44	9.89	81.73	46.50	119.02	102.00
Ceiling fans	10.23	7.71	21.13	20.80	33.12	36.94	44.56	52.36
Televisions	3.46	1.76	12.47	6.44	27.54	14.57	47.07	25.58
Total	15.00	8.09	89.66	45.00	223.01	161.59	399.00	377.75
Savings from BAU	4%	2%	13%	7%	20%	14%	24%	23%

is similar between the two scenarios, hot water provided by electric and liquid petroleum gas heaters could be reduced by around 15% in 2035 through subsidies (SI figure S7).

Uncertainties and gaps

There are several uncertainties inherent in assessing future emissions and policies in a developing country like India. Data and future trends are first among these. The International Energy Agency (IEA) provides a broad set of data on Indian energy supply and demand, including in buildings. However, regarding use of traditional biomass consumption and the breakdown of energy consumption by building energy service (such as lighting, cooking, and cooling), these data are based primarily on Indian Government estimates, not surveys. To help address these gaps, we also compared IEA data to other surveys of commercial and residential buildings, though found other data to be less comprehensive than IEA's. Projecting forward, there are also significant uncertainties about future energy use: will Indian families shift rapidly to American-style air conditioning, or will they continue to use cooling more moderately, for example? To help in answering this, we calibrate our energy use trend lines against trends in other countries (comparing energy use per m² and per capita GDP, for example). This calibration also reduces the risk that poor data on traditional biomass use today would propagate into the future. However, there remains underlying uncertainty about the extent and pace of future Indian population and income growth.

Other areas of uncertainty include the exact design of future policies and the rigor of implementation. We test several policies and implementation rates, but there are also other possibly policy outcomes. For example, it is possible that building energy codes will move toward net-zero requirements, which means that future buildings must incorporate advanced energy efficiency designs and technologies, and have renewable energy integrated to cover the building's own energy use. Some countries and jurisdictions around the world have goals to require net zero buildings by mid-century. Net-zero code assumptions would result in lower energy use by 2050, assuming India would be prepared to implement these requirements. We also do not test the potential of utility-based demand-side management or energy certificate trading schemes to limit energy use in large commercial buildings. Such policies

would likely have increased the speed of technology deployment, but they may not change total energy demand by buildings by 2050, given our other assumptions. Finally, we did test the impact of future temperature increases on building energy demand, but there is uncertainty in the exact amount of climate change. We did not test a range of climate scenarios because this study was primarily focused on exploring policy impacts on emissions.

Conclusions

India, like many developing countries, is at a crossroad with both energy demand and the number of buildings increasing rapidly. Indian policy makers, however, have many opportunities through improved energy performance to reduce the energy and emissions footprints of future Indian buildings. Implementing a range of energy efficiency policies robustly can reduce total Indian energy use by 22% and electricity consumption by 40% in 2050 compared to the BAU scenario. Building energy codes have the strongest potential for improving energy efficiency, assuming robust implementation, because most of India's future building stock has yet to be built. Appliance standards and labels can also play a significant role, and programs to retrofit existing buildings can ensure that inefficient buildings do not endure. For all energy efficiency policies, well-coordinated, consistent implementation and strong compliance are important to achieving results. The deployment of solar water heaters also has a significant impact in the future in reducing the use of fossil fuels, even in the absence of large or long-lasting subsidies.

Building energy efficiency policies studied in this paper could lead to a 29% reduction in emissions intensity per unit of GDP below 2005 levels by 2030 (26% reduction in BAU), compared to the 33%–35% reduction goal set in India's NDC. Moreover, buildings have long life spans and long-lasting impacts; implementing energy efficiency policies in buildings can also avoid locking in inefficient, carbon-intensive infrastructure. Benefits of these policies also extend beyond the energy system. These policies can help improve the thermal comfort of end users and reduce their operational energy costs. Meanwhile, they also have implications for the energy supply system due to the impact on power generation capacity needed for the future.

Several steps are critical to ensuring these benefits are fully achieved. First, it is important to develop systematic building energy policies. This includes having policies in place for various building types, improving stringency of these policies over time, and developing a plan laying out pathways for future improvement. Second, strong compliance is the key. As shown in this analysis and previous studies, robust compliance can help policies achieve their intended benefits. To improve compliance, it requires building capacity in Indian states and cities, developing a monitoring and evaluating system, and tracking and reporting the progress over time. Studies also showed that in places that just started to develop building energy policies and lacked capacity, using third-party inspectors in the building design and construction process is an effective way of improving compliance. Third, having a coordinated policy process contributes to the effectiveness of policies. Policies of the buildings sector do not only affect energy use in buildings, but also have impact on the demand for electricity generation as well as the demand for iron and steel and cement. Thus, a coordinated process of facilitating communication among different stakeholders and across sectors is useful.

Buildings in the future can simultaneously meet the needs of Indian families and businesses for comfortable space and play a key role in helping the country meet its clean growth goals. Improving energy performance in buildings through expanded use of energy efficiency measures and renewable energy can help India achieve sustainable and economic goals such as reducing energy use and GHG emissions, improving urban air quality, and ensuring strong economic growth and competitiveness.

Acknowledgments

The authors are grateful for research support provided by the Shakti Sustainable Energy Foundation. The authors are also thankful for editorial support by Aaron Staniszewski and Artur Denysenko from the Pacific Northwest National Laboratory (PNNL) and inputs provided by the Building Efficiency Accelerator. PNNL is operated for DOE by Battelle Memorial Institute under contract DE-AC5-76RL01830. The views and opinions expressed in this paper are those of the authors alone.

ORCID iDs

Sha Yu  <https://orcid.org/0000-0002-2551-7458>

References

- [1] UNFCCC 2016 INDCs as communicated by Parties (www4.unfccc.int/submissions/INDC/Submission%20Pages/submissions.aspx)
- [2] Fawcett A A, Iyer G C, Clarke L E, Edmonds J A, Hultman N E, McJeon H and Cand Shi W 2015 Can Paris pledges avert severe climate change? *Science* **350** 1168–9
- [3] Admiraal A *et al* 2015 *Assessing Intended Nationally Determined Contributions to the Paris Climate Agreement* (The Hague: PBL Netherlands Environmental Assessment Agency) p 52
- [4] IEA 2015 *Energy and Climate Change—World Energy Outlook Special Briefing for COP 21* (Paris: International Energy Agency)
- [5] Bosetti V, Carraro C and Tavoni M 2009 Climate change mitigation strategies in fast-growing countries: the benefits of early action *Energy Econ.* **31** S144–51
- [6] Pacala S and Socolow R 2004 Stabilization wedges: solving the climate problem for the next 50 years with current technologies *Science* **305** 968–72
- [7] Lucon O *et al* 2014 Buildings, in climate change 2014: mitigation of climate change *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* ed O Edenhofer *et al* (Cambridge: Cambridge University Press)
- [8] IEA 2013 *Transition to Sustainable Buildings: Strategies and Opportunities to 2050* (Paris: International Energy Agency) p 284
- [9] IEA 2015 *India Energy Outlook—World Energy Outlook Special Report* (Paris: International Energy Agency)
- [10] IEA 2015 *Building Energy Performance Metrics: Supporting Energy Efficiency Progress in Major Economies* (Paris: International Energy Agency)
- [11] UNEP 2007 *Buildings and Climate Change—Status, Challenges and Opportunities* (Paris: United Nations Environmental Programme) p 78
- [12] Gokul C I *et al* 2015 The contribution of Paris to limit global warming to 2 °C *Environ. Res. Lett.* **10** 125002
- [13] Chaturvedi V *et al* 2014 Long term building energy demand for India: Disaggregating end use energy services in an integrated assessment modeling framework *Energy Policy* **64** 226–42
- [14] Yu S *et al* 2014 A long-term, integrated impact assessment of alternative building energy code scenarios in China *Energy Policy* **67** 626–39
- [15] Yu S *et al* 2017 Improving building energy efficiency in India: State-level analysis of building energy efficiency policies *Energy Policy* **110** 331–41
- [16] Bhattacharyya S C 2015 Influence of India's transformation on residential energy demand *Appl. Energy* **143** 228–37
- [17] van Ruijven B J *et al* 2011 Model projections for household energy use in India *Energy Policy* **39** 7747–61
- [18] Rawal R *et al* 2014 *Residential buildings in India: energy use projections and savings potential* Global Buildings Performance Network Paris
- [19] Pachauri S and Jiang L 2008 The household energy transition in India and China *Energy Policy* **36** 4022–35
- [20] Chandel S S, Sharma V and Marwah B M 2016 Review of energy efficient features in vernacular architecture for improving indoor thermal comfort conditions *Renew. Sustain. Energy Rev.* **65** 459–77
- [21] Praseeda K I, Reddy B V V and Mani M 2016 *Embodied and operational energy of urban residential buildings in India* *Energy Build.* **110** 211–19
- [22] Kim S H *et al* 2006 The objects framework for integrated assessment: hybrid modeling of transportation *Energy J.* **27** 63–91
- [23] Eom J *et al* 2012 China's building energy demand: long-term implications from a detailed assessment *Energy* **46** 405–19
- [24] Yu S *et al* 2014 Scenarios of building energy demand for China with a detailed regional representation *Energy* **67** 284–297
- [25] IESS 2014 *India Energy Security Scenarios* (www.indiaenergy.gov.in/default.php)

- [26] World Bank 2015 *World Development Indicators* (Washington, DC: The World Bank)
- [27] Ellis P and Roberts M 2015 *Leveraging Urbanization in South Asia: Managing Spatial Transformation for Prosperity and Livability* (Washington, DC: World Bank)
- [28] IMF 2015 *World Economic Outlook Database* (Washington, DC: International Monetary Fund)
- [29] O'Neill B C, Kriegler E, Ebi K L, Kemp-Benedict E, Riahi K, Rothman D S and Solecki W 2017 The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century *Glob. Env. Change* **42** 169–80
- [30] Moss R H *et al* 2010 The next generation of scenarios for climate change research and assessment *Nature* **463** 747–56
- [31] Kumar S *et al* 2010 *Total Commercial Floorspace Estimates for India* (New Delhi: Energy Conservation and Commercialization (ECO-III))
- [32] NSSO 2009 *India—Housing Condition Survey, July 2008–June 2009, NSS 65th Round* (New Delhi: National Sample Survey Office, Ministry of Statistics and Programme Implementation, Government of India)
- [33] Zhou Y, Eom J and Clarke L 2013 The effect of global climate change, population distribution, and climate mitigation on building energy use in the US and China *Clim. Change* **119** 979–92
- [34] Myllyvirta L and Nandikesh Sivalingam S D 2016 *Out of sight: How coal burning advances India's air pollution crisis* (Bangalore: Greenpeace)
- [35] IPCC 2007 *Climate Change 2007: Impacts, Adaptation and Vulnerability* (Cambridge: Cambridge University Press)
- [36] Chaturvedi V *et al* 2014 Long term building energy demand for India: Disaggregating end use energy services in an integrated assessment modeling framework *Energy Policy* **64** 226–42
- [37] Jain A *et al* 2017 *Roadmap to Fast Track Adoption and Implementation of Energy Conservation Building Code at the Urban and Local Level* (New Delhi: Alliance for an Energy Efficient Economy)
- [38] Yu S *et al* 2013 *Using Third-Party Inspectors in Building Energy Codes Enforcement in India* (Richland, WA: Pacific Northwest National Laboratory)
- [39] Shui B 2012 *Third Parties in the Implementation of Building Energy Codes in China* (Washington, DC: American Council for an Energy Efficient Economy)
- [40] Kate Taylor C M 2011 *Community Wide Retrofits: International Best Practices for the Canadian Retrofit Sector* (Canada: Green Communities Canada)
- [41] Humanity H F 2013 *Residential Energy Efficiency for Low-Income Households in Eurasia (REELIH)* (Bratislava: Habitat for Humanity International)
- [42] Harvey L D D 2009 Reducing energy use in the buildings sector: measures, costs, and examples *Energy Effici.* **2** 139–163
- [43] NRDC and ASCI 2013 *Saving Money and Energy: Case Study of the Energy-Efficiency Retrofit of the Godrej Bhavan Building in Mumbai* (New Delhi: Natural Resources Defense Council and Administrative Staff College of India)
- [44] Evans M *et al* 2015 *Unleashing Energy Efficiency Retrofits through Energy Performance Contracts in China and the United States* (Washington, DC: Pacific Northwest National Laboratory and Lawrence Berkley National Laboratory)