nature climate change

LETTERS

PUBLISHED ONLINE: 19 OCTOBER 2014 | DOI: 10.1038/NCLIMATE2414

Household electricity access a trivial contributor to CO_2 emissions growth in India

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Impetus to expand electricity access in developing nations is urgent[1]. Yet aspirations to provide universal access to electricity are often considered potentially conflicting with efforts to mitigate climate change[2]. How much newly electrified, largely poor, households raise emissions, however, remains uncertain. Results from a first retrospective analysis show that improvements in household electricity access contributed 3–4% of national emissions growth in India over the past three decades. Emissions from both the direct and indirect electricity use of more than 650 million people connected since 1981 accounted for 11–25% of Indian emissions growth or, on average, a rise of 0.008–0.018 tons of CO_2 per person per year between 1981 and 2011. Although this is a marginal share of global emissions, it does not detract from the importance for developing countries to start reducing the carbon intensities of their electricity generation to ensure sustainable development and avoid future carbon lock-in[3,4]. Significant ancillary benefits for air quality, health, energy security and efficiency may also make this attractive for reasons other than climate mitigation alone[5,6].

Access to electricity services is fundamental to development, as it enables improvements in human quality of life. Recent empirical studies have quantified a range of benefits of better electricity access and reliability for income and employment generation, gender equity, health, entrepreneurship and education[7–9]. People without electricity are denied the most basic services, from street lighting that can improve safety at night, to mobile phone charging that is vital for communication. Tasks such as milling and grinding cereals that ordinarily require the push of a button can, for the unelectrified, take days of human labour and drudgery, trapping them in subsistence living.

Despite general recognition of the critical importance of electricity, India today hosts the world's largest population without access to it. According to the 2011 Census, a third of all households in the country, or almost 400 million people, live without this basic service[10]. More than 90% of the unelectrified live in rural areas, and for many that are connected electricity supply remains highly unreliable[9]. Providing universal and reliable access to affordable electricity is essential. Yet significant barriers exist to electrifying rural areas in most developing nations, including India[11,12]. Overcoming these barriers requires strengthening policy and institutional frameworks and additional investments[13].

Providing a minimum amount of basic electricity access universally is an urgent short-term imperative. However, ultimately the objective is to extend the benefits of electricity services so as to sustain escape from poverty, and provide more equitable opportunities for livelihood creation and long-term economic development. Providing energy that enables this broader development, beyond

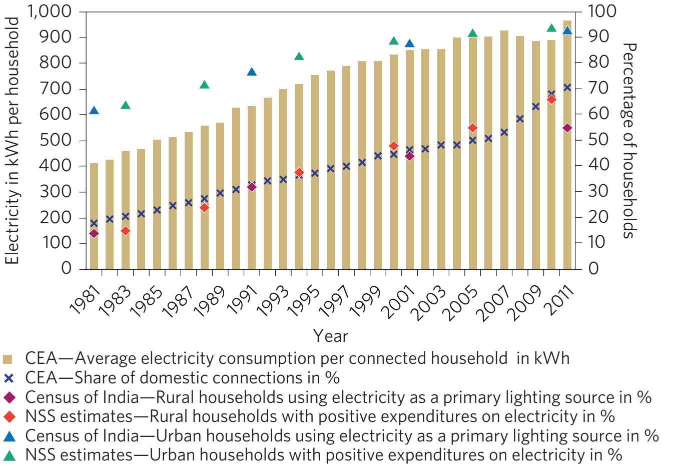

Figure 1 | Estimates of rural, urban and national household access rates, and average direct household electricity use per connected household between 1981 and 2011 from the Central Electricity Authority (CEA) and National Sample Survey (NSS) data sets.

meeting just basic household needs, could lead to larger increases in energy demand[14]. Finding sustainable pathways to meet this growing demand remains a pressing challenge for much of the developing world.

Nations facing the biggest challenge in providing modern energy access have historically contributed the least to climate change[15]. However, this is unlikely to continue as, in many emerging nations, large populations without access to modern energy services already coexist with populations living affluent lifestyles and having large carbon footprints. This has given rise to growing concern about the emissions implications of better access to modern energy in the developing world. Understanding the contribution to historical emissions growth of changes in electricity access can provide insights for avoiding any potential future trade-offs between universal electrification and climate change mitigation goals.

Existing evidence suggests that meeting the energy needs of the poor is unlikely to contribute significantly to global greenhouse gas emissions[16,17]. Recent studies that have assessed the emissions implications of eradicating energy poverty globally or achieving universal modern energy access for cooking and electricity use in homes have done so prospectively. They conclude that these efforts would contribute only marginally to greenhouse gas emissions over the next decades.

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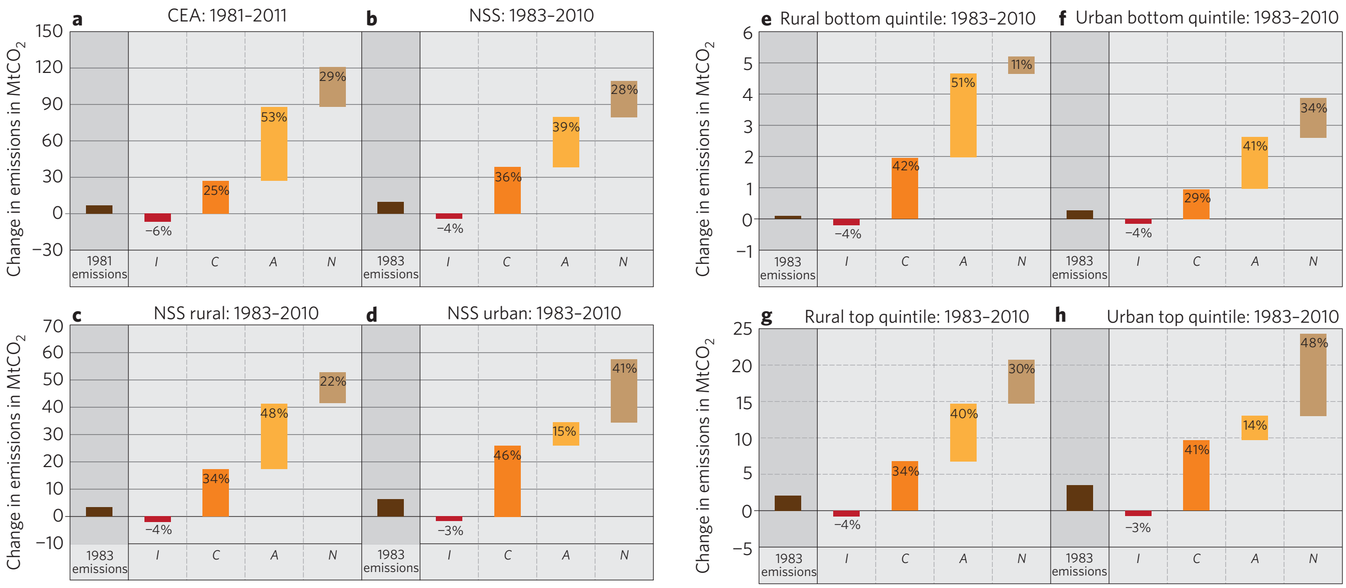

Figure 2 | Decomposition of changes in CO_2 emissions from direct household electricity use. Results of the decomposition analysis for changes in CO_2 emissions from direct household electricity use into four factors—carbon intensity of electricity production (*I*), average consumption per connected household (*C*), share of households with connections or access (*A*), and the total number of households (*N*)—are presented. **a**,**b** CEA and NSS data sets respectively; **c**,**d** rural and urban households separately; **e**,**f** poorest rural and urban quintiles, respectively; **g**,**h** richest rural and urban quintiles, respectively. Base-year emissions (1981 for CEA and 1983 for NSS) are shown on the left-hand side of each panel. The percentage contribution of each effect to the total change in emissions is also depicted on each bar.

This work, for the first time, analyses the emissions implications of better access retrospectively, using historical data from India. India is an ideal case for such an analysis because of its large unelectrified population, the scale of electrification it has already achieved, and its growing energy demand and emissions. In 2011, India emitted 1,745 $MtCO_2\ yr^{-1}$ according to the International Energy Agency (IEA; ref. 18). The electricity sector's contribution to total national CO_2 emissions rose from less than 30% in 1981 to more than 45% by 2011, increasing more than tenfold to 795 $MtCO_2\ yr^{-1}$ in 2011. Over the past three decades, household electricity use has also contributed a growing share of total national CO_2 emissions, accounting for 20% of electricity sector emissions in 2011. Between 1981 and 2011, household electricity access improved from 26% to 67% according to census sources[10], or from 25% to 74% according to national surveys[19]. According to data for the same period from India's Central Electricity Authority (CEA), the share of households connected increased from 19% to 71% (ref. 20). In other words, more than 650 million Indians gained access to electricity over these thirty years. Two-thirds of all households that were connected to electricity during this period were rural. Average annual electricity use among those connected remains very low, despite more than doubling from about 400 kWh per household in 1981 to more than 900 kWh per household in 2011 (Fig. 1). By comparison in 2011, the average household consumption of electricity in China was about 1,200 kWh, whereas in the USA it was more than 10,000 kWh.

This study uses two national data sets to analyse changes in CO_2 emissions from electricity use in India between 1981 and 2011, employing a standard index decomposition method (see Methods for data sources and methodology). Emissions changes are decomposed into four effects, including the carbon intensity of electricity production (*I*), electricity use per connected household (*C*), share of households with access (*A*), and total number of households (*N*). Results of the decomposition analysis applied to the two data sets, one from the CEA and the other constructed from national surveys (Supplementary Text and Supplementary Table 1), show that growing electricity use per connected household and share of households with access made the largest contribution to increasing emissions from household electricity use. Growth in the share of households with access contributed between 39% and 53% to the rise in CO_2 emissions from household electricity use between 1981 and 2011, whereas increasing electricity use per connected household contributed between 25% and 36% (Fig. 2a,b). Thus, improvements in household electricity access accounted for a rise in emissions of 43–64 $MtCO_2$, which was 3–4% of the rise in total national CO_2 emissions during this period. Growth in the total number of households also had a large positive contribution to emissions growth during this period (about 30%), consistent across the two data sources. Finally, changes in carbon intensity of electricity production had a slight negative effect on emissions growth between 1981 and 2011. This was due to improvements in the efficiency of electricity generation, specifically over the past decade, also noted in other studies[21] (see Supplementary Table 2 for decomposition results reported by decade). Variations in the contributions of the individual factors to emissions rise among the two data sources stem from differences in the underlying data on household access rate and consumption per connected household (see Supplementary Table 1 for data sets used).

Decomposing the emissions increase from household electricity use into the same four effects for different population subgroups using the data set constructed from the national surveys provides further insights into the contribution of each effect to total emissions increase among these groups, and the contribution of each of these groups to the total change. On aggregate, rural households contributed about the same amount to emissions increase from household electricity use as urban households, despite the rural population being two and a half times the size of the urban population. Within rural and urban regions, electricity use among the poorest income quintiles contributed less than 10% of emissions growth from household electricity use in each sector, whereas the richest quintile contributed about half. Moreover, the decomposition analysis performed separately for rural and urban households (Fig. 2c,d) and quintiles shows that access contributed a larger share of the emissions increase for groups that experienced large improvements in the access rate (the bottom and top rural quintiles and bottom urban quintile) over this period (Fig. 2e,f). Thus, growth in the share of households with access contributed only 15% of the increase in emissions from urban household electricity use, but almost half of the increase in emissions from rural household electricity use, where access was as low as 15% in 1981. Thus, the bulk of the Indian population (those in rural areas and in the bottom quintiles) experienced significant improvements in household electricity access during this period. This contributed between about 40% and 50% of the emissions growth from household electricity use for these groups. However, in absolute terms this was a relatively small share of total national emissions growth. By contrast, growth in consumption per connected household and in the total number of households together contributed 87% of the emissions increase from household electricity use for the top urban quintile (Fig. 2g,h).

It can be argued that better access to electricity contributes to significantly more than just emissions from direct household use. Electrification aids households to participate in the formal market economy, which in turn engenders changes in lifestyles and consumption patterns[22]. Existing studies analysing direct and indirect household energy use and emissions have found a large gradient in the direct and indirect energy use and emissions between poor and rich and rural and urban Indian households[23–25]. Here, a range of three to seven is used for the ratio of direct to total (direct plus indirect) electricity use, employing existing estimates of direct commercial to total commercial household energy use across different Indian socio-economic groups from ref. 23. As the data does not allow one to distinguish how much electricity is consumed by newly electrified and previously electrified households, it is conservatively assumed that each newly electrified household consumed an amount equivalent to the average rural direct household electricity use in each year over the past three decades. This implies that average direct electricity use for the newly electrified increased gradually from 140 kWh to 455 kWh per connected household between 1981 and 2011, which is also within the band of energy poverty minimum thresholds proposed by various bodies: the IEA proposes 250–500 kWh (ref. 26), the UN Secretary-General's Advisory Group on Energy and Climate Change (AGECC) proposes 50–100 kWh (ref. 27) and Practical Action proposes 120 kWh (ref. 28).

The total electricity use of the newly connected, depending on whether a low ratio of three or high ratio of seven is assumed for the share of direct to total household electricity use, thus accounted for 156 $MtCO_2$ to 363 $MtCO_2$ of emissions increase over the past three decades, or 11% to 25% of national CO_2 emissions increase since 1981. In other words, the direct and indirect electricity use of the more than 650 million Indians connected since 1981 accounted for a rise of 0.008–0.018 tons of CO_2 per person per year, on average, over the past three decades (including power system losses due to transmission and distribution).

What does this imply for the future? India certainly has the technical and economic capacity to connect its remaining unelectrified population within a decade, and the need and urgency of doing so is widely acknowledged. Centralized fossil-based systems continue to remain the mainstay of electricity generation in India and other developing nations, as these are the most familiar and perceived to have least cost. As these countries electrify their vast unelectrified populations, leapfrogging to new renewable and low-carbon technologies may be desirable—but how much this will contribute to global CO_2 mitigation efforts is uncertain. Choosing low-carbon options will, however, have significant ancillary benefits for air quality, health, energy security and efficiency, employment, technical capacity, and global competitiveness, among other goals, all of which might still make the low-carbon options attractive[5,6]. Decarbonizing the energy systems in developing nations today can also reduce the higher cost of delayed mitigation action and avoid technological lock-in for these nations[3,4]. Furthermore, in some areas (regions of low population and demand densities distant from existing grids), decentralized renewables may already be cost-competitive[29]. Systematic and broad analyses of the costs and benefits of different low-carbon alternatives, vis-à-vis conventional fossil options, are needed to better inform these choices.

In the short-term, ending poverty should be an overriding priority for developing countries. Given the present abysmally low levels of average energy use in rural and poor households, electricity demand can be expected to rise—and, indeed, must to raise living standards. Rural electricity use has risen slightly faster, on average, than urban use in the past decade, reflecting latent demand. However, it is still less than half that of urban electricity use today (Supplementary Fig. 1). Beyond disparities between the average rural and urban user, the distribution of electricity use is starkly unequal within the country. Even if it is conservatively assumed that the carbon intensity of electricity production remains unchanged from its present level, and rural electricity demand grows aggressively over the next two decades as a consequence of new applications of electricity (for example, information and communication technologies) and/or quicker diffusion of new appliances (for example, electric induction stoves), the newly electrified in India are unlikely to contribute significantly to global or even national emissions growth.

Methods

Two national sources of data on electricity access and use are employed in this study (see Supplementary Text for more details on the sources used and indicators constructed and see Supplementary Table 1 for the data sets). Annual data on household and national electricity sales (consumption) and number of household connections are sourced from the annual statistical reports of the CEA for the period 1981–2011[20]. In addition, bottom-up estimates of household electricity access, use, population and household size are derived from the large sample quinquennial rounds of the nationally representative Household Consumer Expenditure Surveys (HCES) conducted by the National Sample Survey Organisation (NSSO; ref. 19). This is, in fact, the only source of data from which it is possible to derive estimates of electricity access and consumption separated by rural and urban residence and for different population subgroups over time. The large quinquennial rounds cover the years 1983, 1987–88, 1993–94, 1999–00, 2004–05 and 2009–10. Aggregated data on electricity sales to domestic or household consumers from the CEA reports and bottom-up estimate of total household electricity consumption from the NSSO household surveys are consistent (see Supplementary Fig. 2 for a comparison of estimates from the two data sources). There are, however, some differences between the data sources on estimates of the share of households with access or connection, and the average electricity use per connected household (see Fig. 1 and Supplementary Fig. 1). Furthermore, data on the total number of households are taken from the Indian censuses[10]. Finally, annual estimates of national and sectoral CO_2 emissions from electricity production, and the amount of total electricity production, that are used to estimate the carbon intensity of electricity production are sourced from the International Energy Agency[18]. Other greenhouse gases, biospheric CO_2, and aerosols are not included in this analysis as they correlate less with personal electricity consumption and use.

For the decomposition analysis the additive logarithmic mean Divisia index (LMDI) is employed, which is considered a preferred method[30]. Changes in total emissions from electricity use are decomposed into four underlying factors.

$$E = I * C * A * N$$

where

$E = CO_2$ emissions from electricity use;

$I = E/P$, carbon intensity of electricity production P

$C = U/HH_A$, the average use of electricity (U) per household with access (HH_A)

$A = HH_A/HH_N$, the share of households with access (HH_A) to the total number of households (HH_N)

$N = HH_N$, total number of households

The decomposition of the change in CO_2 emissions from electricity use from time period 0 to period T into the contribution from the change in the four different factors is then done as follows:

$$E_T - E_0 = \Delta E_{\text{total}} = \Delta E_I + \Delta E_C + \Delta E_A + \Delta E_N$$

where

$$\Delta E_I = L[E(T),E(0)]LN\left(\frac{I(T)}{I(0)}\right)$$

$$\Delta E_C = L[E(T),E(0)]LN\left(\frac{C(T)}{C(0)}\right)$$

$$\Delta E_A = L[E(T),E(0)]LN\left(\frac{A(T)}{A(0)}\right)$$

$$\Delta E_N = L[E(T),E(0)]LN\left(\frac{N(T)}{N(0)}\right)$$

where L is the logarithmic mean given by

$$L[E(T),E(0)] = \frac{E(T)-E(0)}{\ln(E(T))-\ln(E(0))}$$

Results from the decomposition analysis are used to calculate how much of the increase in emissions from direct household electricity use between 1981 and 2011 was attributable to changes in each of the four factors, including improvements in household electricity access. The calculated change in amount of emissions is then divided by the total rise in national emissions in India between 1981 and 2011 to estimate the percentage contribution to the change in total national emissions during this period.

The attribution of emissions due to improvements in household electricity access can also be estimated using other methods. This is a first attempt to do so for India using the LMDI method. Better data availability in the future should allow the application of alternative methods and to other national contexts as well.

Received 4 July 2014; accepted 22 September 2014; published online 19 October 2014

References

1. Secretary-General UN *A Vision Statement by Ban Ki-moon Secretary-General of the United Nations — Sustainable Energy for all* (United Nations, 2011).
2. Moss, T., Roger Pielke, J. & Bazilian, M. *Balancing Energy Access and Environmental Goals in Development Finance: The Case of the OPIC Carbon Cap* (Center for Global Development, 2014).
3. Rogelj, J. *et al.* Halfway to Copenhagen, no way to 2 °C. *Nature Clim. Change* **3,** 81–83 (2009).
4. Bertram, C. *et al.* Carbon lock-in through capital stock inertia associated with weak near-term climate policies. *Technol. Forecast. Soc. Change* http://dx.doi.org/10.1016/j.techfore.2013.10.001 (2013).
5. Wilkinson, P. *et al.* Public health benefits of strategies to reduce greenhouse-gas emissions: Household energy. *Lancet* **374,** 1917–1929 (2009).
6. IPCC in *Climate Change 2014: Mitigation of Climate Change* (eds Edenhofer, O. *et al.*) (Cambridge Univ. Press, 2014).
7. Khandker, S. R., Samad, H. A., Ali, R. & Barnes, D. F. Who benefits most from rural electrification? Evidence in India. *Energy J.* **35,** 75–96 (2014).
8. Dinkelman, T. The effects of rural electrification on employment: New evidence from South Africa. *Am. Econ. Rev.* **101,** 3078–3108 (2011).
9. Rao, N. D. Does (better) electricity supply increase household enterprise income in India? *Energy Policy* **57,** 532–541 (2013).
10. Registrar General of India *Data on Housing, Table H Series* (Census of India, 2011).
11. Barnes, D. F. *The Challenge of Rural Electrification: Strategies for Developing Countries* (RFF Press, 2007).
12. Bhattacharyya, S. C. Energy access programmes and sustainable development: A critical review and analysis. *Energy Sustain. Dev.* **16,** 260–271 (2012).
13. GEA *Global Energy Assessment — Toward a Sustainable Future* (Cambridge Univ. Press and the International Institute for Applied Systems Analysis, 2012).
14. Nilsson, M. *et al. Energy for a Shared Development Agenda: Global Scenarios and Governance Implications* (Stockholm Environment Institute, 2012).
15. Matthews, H. D. *et al.* National contributions to observed global warming. *Environ. Res. Lett.* **9,** 014010 (2014).
16. Chakravarty, S. & Tavoni, M. Energy poverty alleviation and climate change mitigation: Is there a trade off? *Energy Econ.* **40,** S67–S73 (2013).
17. Pachauri, S. *et al.* Pathways to achieve universal household access to modern energy by 2030. *Environ. Res. Lett.* **8,** 024015 (2013).
18. IEA *CO_2 Emissions from Fuel Combustion Statistics* (OECD and IEA, 2013).
19. NSSO *Household Consumer Expenditure Surveys* (National Sample Survey Organization, Ministry of Statistics and Program Implementation).
20. CEA *All India Electricity Statistics General Review* (Central Electricity Authority, Ministry of Power).
21. Shrestha, R. M., Anandarajah, G. & Liyanage, M. H. Factors affecting CO_2 emission from the power sector of selected countries in Asia and the Pacific. *Energy Policy* **37,** 2375–2384 (2009).
22. Pachauri, S. & Spreng, D. in *Tackling Long-Term Energy Problems: The Contribution of Social Science* (eds Spreng, D., Flueler, T., Goldblatt, D. L. & Minsch, J.) Ch. 5, 73–96 (Springer, 2012).
23. Pachauri, S. *An Energy Analysis of Household Consumption: Changing Patterns of Direct and Indirect Use in India* (Springer, 2007).
24. Grubler, A. & Pachauri, S. Problems with burden-sharing proposal among one billion high emitters. *Proc. Natl Acad. Sci. USA* **106,** E122–123; author reply E124 (2009).
25. Chakravarty, S. & Ramana, M. V. in *Handbook of Climate Change and India: Development, Politics and Governance* (ed. Dubash, N. K.) 218–229 (Oxford Univ. Press, 2011).
26. IEA *World Energy Outlook 2011* (International Energy Agency (IEA) and the Organisation of Economic Co-operation and Development (OECD), 2011).
27. AGECC *Energy for a Sustainable Future: Summary Report and Recommendations* (The UN Secretary-General's Advisory Group on Energy and Climate Change (AGECC), 2010).
28. Action, P. *Poor Peoples Energy Outlook 2010* (Practical Action, 2010).
29. Narula, K., Nagai, Y. & Pachauri, S. The role of decentralized distributed generation in achieving universal rural electrification in South Asia by 2030. *Energy Policy* **47,** 345–357 (2012).
30. Ang, B. W. Decomposition analysis for policymaking in energy. *Energy Policy* **32,** 1131–1139 (2004).

Acknowledgements

This work uses data from the Ministry of Statistics and Programme Implementation of the Government of India, the Census of India, and India's Central Electricity Authority. I thank my IIASA colleagues in the Energy (ENE) program for useful discussions and comments, and my colleagues in the Communications Department for help with the figures. I am also grateful to A. Grubler, K.R. Smith and D. Spreng for valuable feedback on initial drafts.

Additional information

Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints.

Competing financial interests

The author declares no competing financial interests.