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SHIFTING CURRENTS: OPPORTUNITIES FOR LOW-CARBON ELECTRIC CITIES IN THE GLOBAL SOUTH

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EXECUTIVE SUMMARY

Highlights

- A transition to low-carbon electric cities is an essential strategy for reducing global greenhouse gas emissions and has the potential to provide many benefits to the urban underserved.
- The transition entails three elements: replacing fossil fuel–powered with electrically powered engines and devices (electrification), generating electricity from renewable or fossil fuel–free sources, and implementing energy efficiency measures.
- This paper identifies 34 countries in the global South where electrification may already be a good strategy today, based on their level of urban access to electricity and the carbon intensity of their national power supplies. Electrification is a good strategy to pursue today in all South American cities, and many cities in the Middle East, North Africa, and Asia.
- Not all cities are equally well-placed to begin the transition away from fossil fuel dependency toward clean, low-carbon electricity. We show which cities need to give urgent attention to electricity access—as well as those that have largely tackled access but have unsustainable, high-carbon power systems that urgently need to be decreased in carbon intensity.
- High upfront costs remain the biggest barrier to investing in low-carbon electricity generation and electric devices, but falling technology costs and momentum toward carbon pricing are encouraging.

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Background

Cities will play a major role in climate action and creating a decarbonized, sustainable future. Global electricity use will continue to rise as it is strongly linked to economic growth. In the global South, electricity consumption in cities is increasing much faster than population growth because of the relationship between consumption and economic growth. However, there is potential for this electricity demand to be met from carbon-free or low-carbon sources, and through efficiency measures.

Cities will need to make the transition from fossil fuel dependence to operating as low-carbon "electric cities." This transition entails three types of technological development: shifting from fossil fuel–powered to electrically powered engines and devices, which we term *electrification*, generating electricity from renewable or fossil fuel–free sources, and implementing energy efficiency measures. But not all cities are equally well-placed to begin the transition immediately.

Our Approach

This paper addresses two questions:

- Which cities are currently best positioned to make the transition to electrification?
- What are the costs, barriers to, and enablers of low-carbon electric cities?

It is the first paper to explore the idea of electrification from the perspective of both people's access to electricity and greenhouse gas (GHG) reductions and to propose candidate cities on the basis of these considerations.

The paper uses two criteria to identify cities in the global South that are candidates for electrification today. First, urban access to electricity (i.e., the percentage of people with a household electricity connection) must already be greater than 90 percent. Below this threshold, electrification of fossil fuel–consuming devices may worsen inequities in access.

We use the 90 percent threshold as an indication that a city has developed sufficient wealth and capability to provide electricity access to all citizens, and is well on its way to providing 100 percent access. The 90 percent threshold is, however, arbitrary, and city leaders are encouraged to debate the suitability of this threshold. Consideration should also be given to the quality of access, as reflected by frequency, reliability, safety, and cost.

Second, the carbon intensity of electricity supply must be below a threshold of 600 metric tons of carbon dioxide equivalent per gigawatt hour (tCO_2e/GWh). Above this threshold, shifting to greater use of electricity would only increase emissions over the life cycle of the product or service (Kennedy 2015).

While city-level data on electricity access and the carbon intensity of electricity would be ideal, they do not exist in a comprehensive fashion. Therefore, although we highlight some city-level data, we use national-level data for both criteria to identify cities in the global South that are ideal for development as electric cities today.

Key Findings

There are distinct regional variations in the carbon intensity of national electric grids. In Europe (with the notable exception of Poland), Latin America, much of sub-Saharan Africa, and North America, the national grids are fairly low carbon (IEA 2017). In some countries in Asia, notably China, India, and Indonesia, as well as in South Africa and Australia, the electric grids are highly carbon intensive (IEA 2017).

Access to electricity among urban populations in much of the global South is high, but access rates vary widely in sub-Saharan Africa. Urban access rates in South America, Central America, and the Caribbean exceed 90 percent in all the countries we considered in these regions, with the exception of Haiti (53 percent) (World Bank 2017). In the Middle East and North Africa (MENA) region, Djibouti stands out as the only country with low urban access to electricity, while in Asia, only Myanmar has urban populations with less than 90 percent access to electricity.[1] Urban electricity access shows greatest variability in sub-Saharan Africa, where rates range from 20 percent or less in Chad, Liberia, and South Sudan, to more than 90 percent in Equatorial Guinea, Ethiopia, Ghana, Mauritius, and South Africa (World Bank 2017). Among all continental regions, sub-Saharan Africa has the lowest rates of urban electricity access (World Bank 2017).

Figure ES-1 | **Tomorrow's Low-Carbon Electric Cities? Candidates for the Transition**

CARBON INTENSITY OF ELECTRICITY SUPPLY (2013–2015 AVERAGE)

ACCESS OF URBAN POPULATION TO ELECTRICITY (2014)

	Less than 600 tCO_2e/GWh	**More than 600 tCO_2e/GWh**
More than 90 percent	**Potential electric-city leaders** Accra Addis Ababa Algiers Asunción Bangkok Bogotá Buenos Aires Cairo Caracas Colombo Dhaka Guatemala City Ho Chi Minh City Karachi Kathmandu La Paz Libreville Lima Managua Manila Mexico City Montevideo Panama City Paramaribo Phnom Penh Quito San José (Costa Rica) San Salvador Santiago Santo Domingo São Paulo Tegucigalpa Tehran Tunis **RECOMMENDATIONS:** Cities should aggressively electrify, substituting fossil fuels with electricity while continuing to decarbonize their power supplies.	**High-access polluters** Amman Asmara Baghdad Beirut Casablanca Havana Jakarta Johannesburg Kingston Kuala Lumpur Mumbai Port of Spain Sana'a Shanghai Tripoli Ulaanbaatar **RECOMMENDATIONS:** Cities should prioritize reducing the carbon intensity of their existing power supplies while making sure the enabling conditions are in place for electrification.
Less than 90 percent	**Cleaner, but limited access** Abidjan Brazzaville Dar es Salaam Khartoum Kinshasa Lagos Lomé Luanda Lusaka Maputo Nairobi Windhoek Yangon Yaoundé **RECOMMENDATIONS:** Cities should focus on rapidly increasing power supply from renewable sources and energy efficiency measures and pursue electrification only in communities where high levels of access have been achieved.	**High polluting with limited access** Cotonou Dakar Gaborone Harare Juba Niamey Port-au-Prince Port Louis **RECOMMENDATIONS:** Cities should focus on increasing access and need major investments in renewable power supply before pursuing electrification.

Note: Good candidate cities for electrification have carbon intensities of electricity supply of < 600 tCO_2e/GWh and populations where > 90 percent of residents have access to electricity (bold). This is a representative, not exhaustive, set of cities. This list includes the largest or capital city of countries in the global South using our two criteria.
Sources: IEA 2017 (carbon intensity of the electric grid); World Bank 2017 (percentage of the urban population with access to electricity).

Based on our analysis, we find that electrification is a good strategy to pursue today in many cities across the global South. We have identified 34 such countries in the global South on the basis of our two criteria of high electricity access and relatively low-carbon electricity supplies. In total, these countries contain 105 cities with populations greater than one million people (UN 2014). In broad terms, electrification is a good strategy to pursue in all South American cities, while many others can be found in the Middle East and North Africa region (e.g., Algiers, Cairo, Tehran, Tunis) and Asia (e.g., Bangkok, Dhaka, Ho Chi Minh City, Karachi, Kathmandu, Manila, Phnom Penh). Cities in Ethiopia (Addis Ababa), Gabon (Libreville), and Ghana (Accra) in sub-Saharan Africa also meet the criteria (Table ES-1).

Cities in South Africa, Eritrea, Cuba, China, India, Indonesia, and other parts of Asia and the MENA region have carbon intensities above the 600 tCO_2e/GWh threshold and need to prioritize developing lower-carbon electricity supplies while establishing enabling conditions for substantial electrification. A few major cities in the global South (e.g., Cotonou, Benin; Gaborone, Botswana; Port-au-Prince, Haiti; Niamey, Niger; Dakar, Senegal) have both low access to electricity and carbon-intensive electricity. Most cities in sub-Saharan Africa have sufficiently clean electricity supplies, but fewer than 90 percent of urban residents currently have access to electricity (World Bank 2017). Of the countries we examined where data exist for both criteria, only 3 cities out of the 40 that have more than one million people in sub-Saharan Africa would be suitable for electrification (Accra, Addis Ababa, Kumasi) on the basis of our data; in South and East Asia, only 26 out of 202 cities with more than one million people are good candidates (UN 2014).

Moving Forward

Recommended actions toward low-carbon electrification for cities in the four categories of this study are given in Figure ES-1.

The upfront investment cost of the infrastructure and technologies required to transition to low-carbon electric cities is perhaps the biggest barrier to progress. The infrastructure associated with upgrading existing electricity grids and new technologies to power electric vehicles and even simple devices can require major investments. For example, the price of an electric cookstove (perhaps as much as $150 for an electric induction stove) remains a barrier for the urban poor, especially in sub-Saharan Africa (Kammila et al. 2014). Electric vehicles remain expensive, although they have seen significant cost decreases in recent years, due in large part to steep reductions in the cost of batteries. Electric vehicles are projected to be cost competitive with internal combustion engines by 2022 (Randall 2016).

A range of economic policy initiatives will be needed to accelerate the transition to low-carbon electric cities. Broadly, the production and use of electric devices needs to be incentivized, for example, through subsidies for electric rickshaws, buses, and cars or electric stoves, LED (light emitting diode) lighting, and solar lanterns, and through the provision of electric charging infrastructure for vehicles. Legal and regulatory environments need to broadly support the electrification process by, for example, changing building codes and practices to foster the use of heat pumps in buildings. Other steps include updating procurement processes that mandate zero-emission vehicles in municipal fleets, blending public and private finance to address risk perceptions, and encouraging manufacturers to develop new models of engagement, such as battery leasing.

1. INTRODUCTION: THE URBAN ENERGY TRANSITION

If the United Nations Sustainable Development Goals and the objectives of the Paris Agreement on climate change are to be met, cities everywhere must transition away from a dependence on fossil fuels to reduce their emissions of carbon dioxide (CO_2) and air pollutants that undermine human health. Both agreements recognize the important role that cities play in the global effort to combat climate change and create a decarbonized, sustainable future. The energy strategy with the greatest potential for achieving the urban energy transition involves the widespread use of electricity from low-carbon sources, which include renewable energy from solar and wind, geothermal and hydropower, sustainably harvested biomass, and ocean tides or waves. Low-carbon electricity may be generated either inside or outside city boundaries, with the specific technology dependent on local resource potential.

But the transition involves more than just generating electricity from sustainable sources; it also involves substituting electricity in place of fossil fuels used for transportation, heating, and lighting.

When considering the transition to low-carbon electric cities in the global South, issues of social equity and quality of life are paramount. The energy priority of cities in the global South should be to address the lack of access to clean, reliable, and affordable energy that continues to afflict the urban underserved (Westphal et al. 2017). About 131 million people in urban areas lack access to electricity globally, 95 million in sub-Saharan Africa alone (World Bank 2017). Approximately 482 million people worldwide in urban centers use solid cooking fuels, including 213 million in sub-Saharan Africa, 146 million in East Asia and the Pacific, and 100 million in South Asia (World Bank 2017). Kerosene is one of the primary sources of light for unelectrified populations, but it has high associated fire risks and is a leading cause of child poisoning (Angelou et al. 2013). Moreover, the use of solid fuels for cooking is a major public health issue in the global South. Close to 550,000 premature deaths might have occurred in urban areas in 2010 due to their household use (World Bank 2017). So, the first consideration in assessing the potential for transitioning to low-carbon electric cities is the current level of access to electricity.

Shifting to low-carbon electricity and adopting energy efficiency measures can bring benefits to the urban poor. Both approaches would improve air quality, particularly when existing fossil fuel–fired power generation is located close to cities—every kilowatt-hour (kWh) saved where cities depend on “dirty” electricity grids also means reduced air pollution. More energy-efficient structures and appliances will provide benefits in terms of reduced energy bills and improved economic productivity, comfort, health (reduced illnesses), and climate change resilience (e.g., to heat waves) (Westphal et al. 2017). However, the costs of transitioning to low-carbon electric cities, particularly upfront capital costs, need to be carefully evaluated for their impact.

Other reasons for developing electric cities include a decreased reliance on diminishing fossil fuel reserves; reduced vulnerability to volatile fuel prices for poorer fuel-importing countries; and reduced expenditures on fossil fuel subsidies.

This paper addresses two questions on the transition to low-carbon electric cities:

- Which cities in the global South are currently best positioned to make the shift from fossil fuels to electric power?
- What are the costs, barriers to, and enablers of the transition to low-carbon electric cities?

1.1 The Transition to Low-Carbon Electric Cities

The transition has three core elements:

- Replacing fossil fuel–powered engines, furnaces, and other equipment with electric devices. This shift from direct fossil fuel combustion to electric power is known as clean *electrification* (Table 1). As used in this paper, the term is not to be confused with the process of extending access to electric power.
- Generating electricity from renewable or fossil fuel–free sources, including distributed renewable energy systems, both outside and within the city boundaries.[2]
- Implementing energy efficiency measures, especially building efficiency and more efficient electric appliances and devices that provide comparable or higher levels of service with lower energy input.

Table 1 | Examples of Technologies and Products Suitable for Electrification

FOSSIL FUEL-BASED TECHNOLOGY	ELECTRIC EQUIVALENT
Automobiles with internal combustion engines	Electric vehicles
Diesel buses	Electric buses or streetcars
Liquefied-petroleum-gas (LPG)- or diesel-powered rickshaws	Electric rickshaws
Short-haul air flights	High-speed electric trains
Natural gas or oil furnaces	Ground or air source heat pumps
Charcoal, biomass, propane, LPG, natural gas, or other fossil fuel–powered stoves	Electric stoves
Kerosene, paraffin, or other fossil fuel–powered lanterns	Solar lanterns/LED (light emitting diode) lighting

Source: Stewart et al. 2018.

All three of these core elements are essential for the transformation to low-carbon electric cities and central to many national visions for deep decarbonization, where cities aspire to become low carbon, or even net-zero carbon or carbon neutral (Box 1). The importance of electrification (the shift from fossil fuel combustion to electric power) for reducing emissions is noted in the energy systems chapter of the Intergovernmental Panel on Climate Change's *Fifth Assessment Report* (Bruckner et al. 2014), and further stressed by the International Energy Agency's (IEA's) *Energy Technology Perspectives* (2014). The Deep Decarbonization Pathways Project (2015) has developed pathways for 15 countries[3] to transition to a low-carbon economy in line with keeping the increase in global warming to less than two degrees Celsius. In all the deep decarbonization pathways, electrification and the decarbonization of electricity play a central role. Across the 15 countries, the share of electricity in final energy consumption rises to 40 percent, which represents a doubling between 2010 and 2050. Another recent study for the United States modeled pathways for achieving CO_2 reductions of 80 percent below 1990 levels; by 2050, the main scenario results in electricity comprising more than 50 percent of final energy use (Risky Business Project 2016).

Box 1 | Low-Carbon, Net-Zero-Carbon, and Carbon-Neutral Cities

In the context of climate change mitigation, the terms *low carbon*, *net-zero carbon*, and *carbon neutral* are often used. One way to understand them as they relate to cities is by considering emissions "scopes," or whether the emissions occur within or outside the boundaries of a city. The Greenhouse Gas Protocol defines three scopes for cities.[a] Scope 1 includes *territorial* emissions, or greenhouse gas (GHG) emissions from sources located within the city boundary. Scope 2 emissions include those resulting from the use of grid-supplied electricity, heat, steam, and/or cooling inside the city boundary. Lastly, scope 3 includes all other GHG emissions that occur outside the city boundary as a result of activities taking place within the city boundary, such as out-of-boundary waste (e.g., landfills) and transport (e.g., air travel), and electricity transmission and distribution. Thus, *low carbon* simply means a reduction in carbon emissions in scopes 1, 2, and 3 as compared with a baseline.

Carbon neutral and *net-zero carbon* are often used interchangeably, and many cities are striving to become carbon neutral but are considering only a subset of emissions. However, to become completely carbon neutral, or net-zero carbon, all scope 1, 2, and 3 emissions are reduced to zero through a combination of zero-carbon activities within the city and offsetting ("netting out") activities outside the city. This would include using 100 percent renewable energy (both onsite and offsite), using non motorized or electric transport, and improving waste management (recycling, composting).

Note:
[a] Greenhouse Gas Protocol 2014.

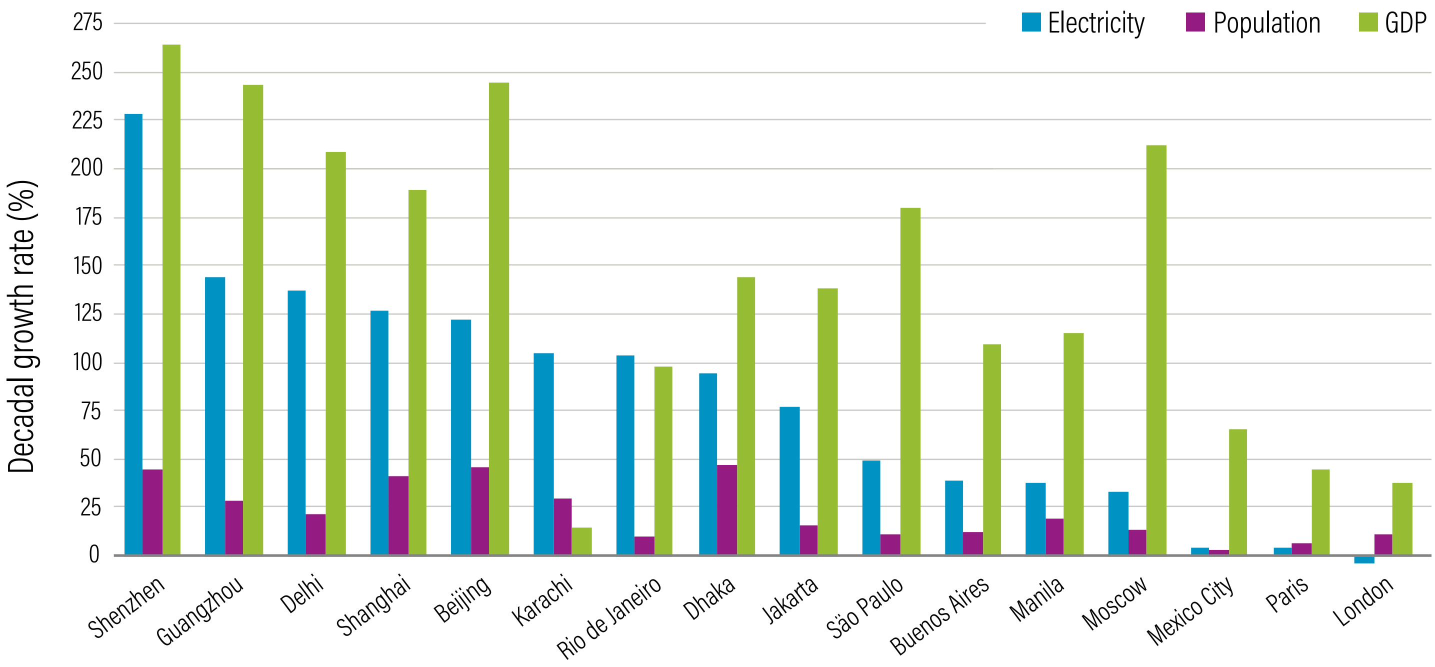
1.2 The Current Status of Electricity Use in Cities

The rate of increase in electricity consumption in many cities in the global South is already far exceeding the population growth rate (see Figure 1). Because electricity use is strongly linked to economic growth (Liddle and Lung 2014) it will continue to rise. However, there is potential to meet this electricity demand from carbon-free or low-carbon sources and to curb demand growth through efficiency measures. The development of electric cities using low-carbon power supplies is thus a critical strategy for addressing the global climate change challenge. Electrification may also enhance the quality of life and the quality of energy services for the urban underserved in the global South.

Two metrics can be used to assess the degree to which a city can be described as a low-carbon electric city: the carbon intensity of its electricity supply,[4] and the share of its electricity that is supplied by low-carbon or carbon-free sources. Figure 2 demonstrates the two measures for global megacities, as of 2010, since good data exist for these cities.

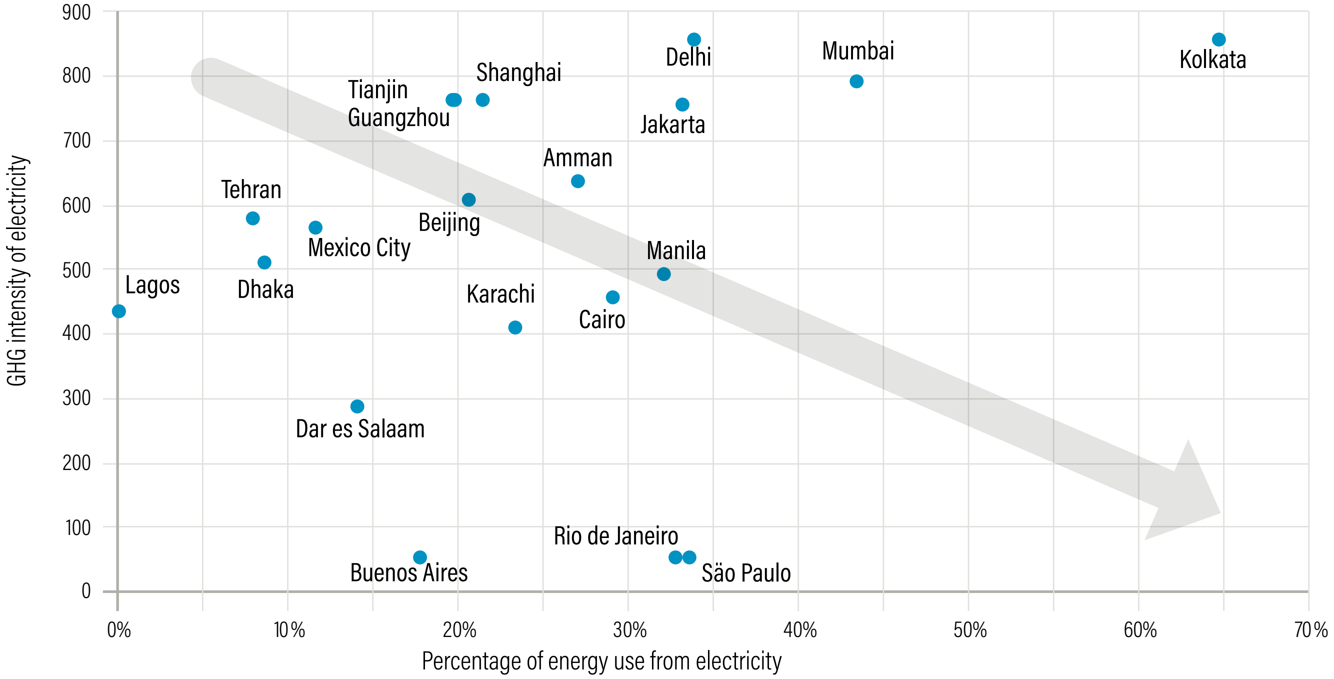
The first measure in Figure 2 is the share of electricity in urban energy consumption. It's determined by accounting for all the end uses of energy in a city—households, businesses, industry, transportation, and so on—then calculating the percentage of end uses that is served by electricity (as opposed to direct combustion of fuels). To assess the share in the global South, we give special attention to megacities, most of which are located at low/

Figure 1 | **Growth of Electricity Use, Population Size, and Gross Domestic Product in Select Megacities, 2001–2011**



Source: Kennedy et al. 2015.

Figure 2 | **Comparative Status of Global Megacities with Respect to Electrification and Decarbonization, 2011**



Source: Kennedy et al. 2015; Kennedy et al. 2017

middle latitudes, because comprehensive energy data are available only for these cities. India's three megacities—Mumbai, Delhi, and Kolkata—have the greatest share of electricity in the energy mix among all megacities considered here (Kennedy et al. 2015; CDP 2015). At the high end is Kolkata, with 65 percent, while Dhaka, Tehran, and Lagos are at the low end, each with electricity accounting for less than 10 percent of the energy mix (Kennedy et al. 2015; CDP 2015). The Chinese megacities of Shanghai, Beijing, Tianjin, and Guangzhou sit between 20 and 30 percent, while megacities of South America (Rio de Janeiro and São Paulo) and Southeast Asia (Manila and Jakarta) are slightly higher, at about 33 percent (Kennedy et al. 2015; CDP 2015).

A high share of electricity in the final mix does not, alone, indicate progress toward improved access to electricity, or reduced carbon content. For example, although Kolkata and Mumbai source more than 40 percent of their energy from electricity, both are energy poor overall, with only 10 gigajoules (GJ) of energy use per capita per year (in 2011), although per capita energy use has been increasing (Kennedy et al. 2015). This compares with about 40 GJ per capita in the megacities of South America and Southeast Asia, and more than 70 GJ per capita in the megacities of China (Kennedy et al. 2015). In contrast, Tehran is energy rich with 91 GJ of electricity consumed per capita per year, but less than 10 percent of its energy is supplied from electricity (Kennedy et al. 2015).

1.3 Electrification and the Carbon Intensity Threshold

There are several approaches to electrification, including replacing internal combustion engines with electric vehicles (EVs), and natural gas furnaces with heat pumps (Kennedy et al. 2014). The success of these technologies and strategies in abating urban greenhouse gas (GHG) emissions depends on the local context: industry, technology, economy, climate, urban form, and changing consumption patterns. Fundamentally, however, their climate mitigation benefit depends most upon the carbon intensity of local electricity supplies (Kennedy et al. 2015). In other words, the case for electrification of cities is compelling only insofar as clean energy sources are available and able to reduce traditional dependence on carbon-based fuels.

Kennedy et al. (2015) identified an intensity of 600 metric tons of carbon dioxide equivalent per gigawatt hour (tCO_2e/GWh) of electricity generated as the threshold for pursuing the transition to a low-carbon electric city. Below this threshold, the transition is expected to reduce urban GHG emissions. The threshold is derived from life cycle emissions studies that estimated the impact of replacing fossil fuel devices with equivalent electric ones and has been verified by the IEA (2015). Above the threshold, reductions in furnace and tailpipe emissions due to electrification are more than offset by upstream emissions, such as those from smokestacks at power plants (Box 2).

1.4 Our Approach

To identify candidate cities in which to promote low-carbon electrification while addressing broader social concerns about access, we have developed a guidance framework (Figure 3). The framework contains two key criteria. First, urban access to electricity (i.e., the percentage of people with a household electricity connection) must already be greater than 90 percent. Below this threshold, electrification of fossil fuel–consuming devices may worsen inequities in access. Second, the carbon intensity of electricity supply must be below a threshold of 600 tCO_2e/GWh. Above this threshold, shifting to greater use of electricity only increases emissions over the life cycle of the product or service.

In Section 2, we apply the framework to cities in the global South. We use national data from the World Bank on the percentage of urban dwellers with access to electricity to estimate access to electricity in major cities. We then examine the carbon intensity of electricity supplies at the national level in countries of the global South, using data from the International Energy Agency. We compare those intensities to the recommended carbon intensity threshold (Kennedy et al. 2015).

In Section 3, we review academic and institutional literature on the costs, barriers, and enabling mechanisms for shifting to low-carbon electricity supplies and technologies in the global South. Case studies reported in the literature highlight the costs and benefits of such a shift, with each study providing valuable insights about the barriers to and enablers of low-carbon electric cities in local and regional contexts. We place these insights in the context of the broader financial, technological, policy, and governance barriers and enablers identified by the World Bank and IEA. Ultimately, this work points us toward cities and regions where opportunities for low-carbon electrification are expected to be most sustainable—socially, economically, and environmentally.

Box 2 | The 600-Tonne Carbon Intensity Threshold

The carbon intensity threshold of 600 metric tons of carbon dioxide equivalent per gigawatt hour (tCO_2e/GWh) of electricity generation is important when substituting fossil fuel engines and furnaces with electrical equivalents. The threshold was identified from global life cycle studies of ground-source heat pumps, electric cars, vans, heavy trucks, passenger trains, and freight trains.[a] Life cycle emissions include both direct emissions and upstream "embodied" emissions. For each of these technologies, the carbon intensity of electricity at which electrification produces a reduction in life cycle greenhouse gas (GHG) emissions falls in the range of about 500 to 700 tCO_2e/GWh.[b] We use 600 tCO_2e/GWh as the threshold because it is the midpoint, and most values cluster around it. Switching to electric modes in cities or countries whose electricity supplies are above the threshold will only increase overall emissions. For example, shifting to electric vehicles would replace tailpipe emissions with even greater power sector emissions.

The 600 tCO_2e/GWh threshold applies to the average emissions intensity of electricity supply, not the marginal emissions intensity. When considering the impact of electrification on GHG emissions, one perspective is that the marginal emissions intensity should be used. That is, when deciding whether there are emissions benefits from shifting from a fossil fuel–consuming device to an electric one, the assessment should be based on the carbon intensity of the next unit of electricity required to implement the change, not the average carbon intensity of the electric supply. There are several issues with this. We are looking at system-wide change, not the change that would result from substituting one unit of technology in a piecemeal fashion. Moreover, calculating the marginal emissions factor is problematic because electricity demand and electricity supply sources vary over time. Moreover, the development of low-carbon electric cities involves electrification along with the two other strategies of energy efficiency and decarbonization. Increases in electricity demand need not occur.

Note that we are not advocating the 600 tCO_2e/GWh threshold as an ideal or even sufficient level of carbon intensity. Cities should strive to get the carbon intensity of their electricity supplies to zero, as fast as possible.

Notes:

[a] Kennedy et al. 2014; Kennedy et al. 2015; IEA 2014.

[b] Kennedy et al. 2014; Kennedy et al. 2015; IEA 2017, 4.

Figure 3 | **Framework for Identifying Cities with Immediate Potential for Low-Carbon Electrification**

		CARBON INTENSITY OF ELECTRICITY SUPPLY (2013–2015 AVERAGE)	
		Less than 600 tCO_2e/GWh	**More than 600 tCO_2e/GWh**
ACCESS OF URBAN POPULATION TO ELECTRICITY (2014)	**More than 90 percent**	**Potential electric-city leaders**	**High-access polluters**
	Less than 90 percent	**Cleaner, but limited access**	**High polluting with limited access**

2. OPPORTUNITIES FOR SHIFTING TO LOW-CARBON ELECTRICITY USE

This section examines the two conditions that must be met if cities are to be good candidates for transitioning to widespread use of low-carbon electric power. The first condition is that a city must already meet a high threshold of energy access; otherwise, electrification could exacerbate challenges of inequitable access. The second is that a city's electricity supply must fall below the 600 tCO_2e/GWh carbon intensity threshold. This threshold determines whether further electrification will reduce GHG emissions—if the generation source is "dirty," shifting to electric power will not help.

Section 2.1 examines electricity access, recognizing the trade-offs that cities in the global South may face when choosing between allocating resources to expand public access to electricity and investing in greater use of electric technologies. Section 2.2 looks at current average levels of carbon intensity in the major world regions, with extended analysis of changes in national values over time given in Appendix A. Section 2.3 combines the analyses to identify global South cities that are currently best suited to pursue low-carbon electrification. Section 2.4 examines the potential impacts of electrification on electricity demand, using the data available for megacities.

2.1 Urban Electricity Access

The first major factor in our analysis is the level of electricity access in cities, which we measure as the percentage of urban residents with a household electricity connection.

We recognize that the issue of access goes beyond the number of connections, and should include factors such as the reliability, cost, and safety of the electricity supply. For example, the World Bank's Sustainable Energy for All initiative has developed a framework that measures electricity access across five tiers using metrics of peak capacity, availability, reliability, quality, affordability, legality, and health and safety (World Bank 2015a). However, in this paper, we have chosen to use a simple binary measure of access in order to make our analysis tractable.

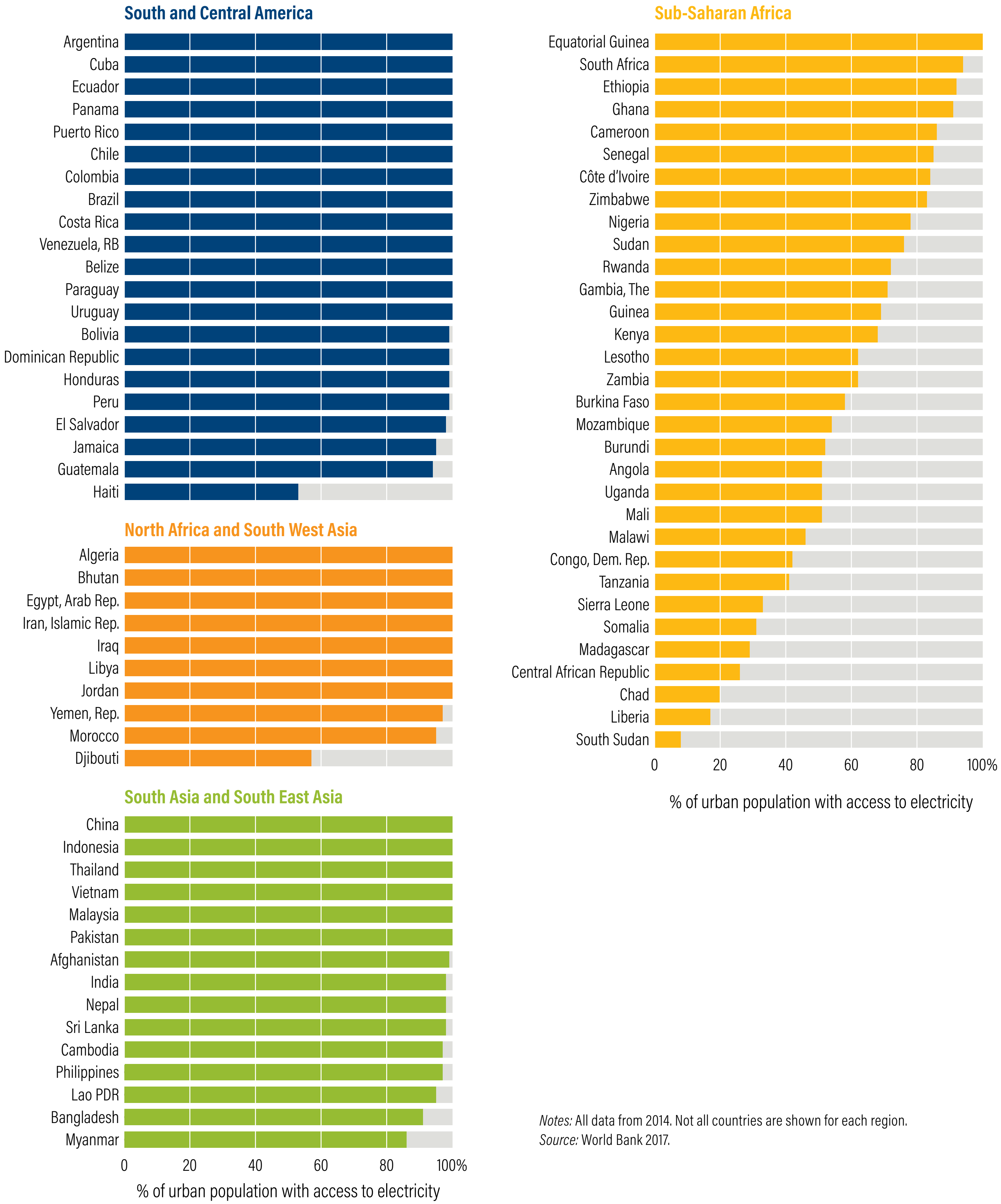
Cities with low levels of access to electricity may prefer, for considerations of equity, to focus their limited resources on increasing access for the urban underserved rather than diverting funds to electrification. However, the two strategies are not mutually exclusive, and there can be complementarities between electrification and access. For example, distributed renewables, such as solar photovoltaics, can both provide electricity access and allow people to shift away from kerosene lighting.

Access to Electricity at the National Scale

Access to electricity among the urban populations of South America, Central America, and the Caribbean is generally high, exceeding 90 percent in all countries considered here, except Haiti (53 percent) (Figure 4) (World Bank 2017). In the Middle East and North Africa, Djibouti stands out as the only country with low urban access to electricity, while in Asia, only Myanmar (86 percent) has an urban population with less than 90 percent access to electricity (World Bank 2017).

Urban electricity access shows greatest variability in sub-Saharan Africa, where rates range from 20 percent or less in Chad, Liberia, and South Sudan, to more than 90 percent in Equatorial Guinea, Mauritius, South Africa, Ethiopia, and Ghana (Figure 4) (World Bank 2017). Among all continental regions, sub-Saharan Africa has the lowest rates of urban electricity access (World Bank 2017).

Figure 4 | **Sub-Saharan Africa Has Lower Rates of Urban Electricity Access than Other Regions (2014)**



Notes: All data from 2014. Not all countries are shown for each region.
Source: World Bank 2017.

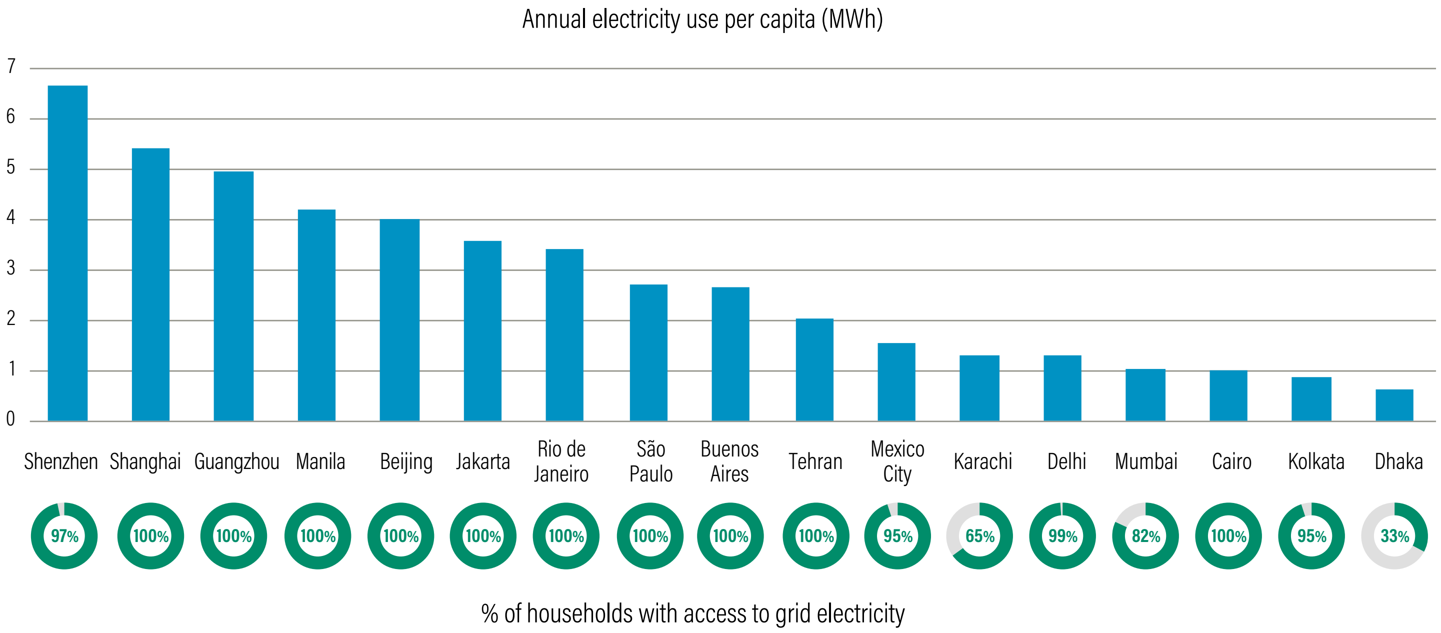
Access to Electricity at the Local Scale

Access rates at the national level do not necessarily reflect conditions at the local or municipal scale; that is, in cities and their neighborhoods (especially informal settlements). Among Indian megacities, for example, access to grid electricity at the metropolitan scale was 82 percent in Mumbai in 2011, compared with 93 percent for the urban population of India as a whole in 2011 (Kennedy et al. 2015; World Bank 2017). Moreover, power outages and voltage fluctuations can be common, further qualifying what “access” means. In Delhi’s informal settlements—the majority of which are not officially electrified—one estimate was that only one-quarter of the population had legal access to electricity in 2007, with most residents gaining access through illegal “hooking” (Dhingra et al. 2008). In one of Africa’s largest informal settlements—Kibera, in the city of Nairobi—electricity reached only 42 percent of residents and only 30 percent of small-to-medium-sized enterprises in 2007 (Karekezi et al. 2008). This compares with an access rate of 74 percent for the urban population of Kenya at the national level during the same period (World Bank 2017). In contrast, Bangkok’s informal settlements had nearly 100 percent access to grid electricity in 2007, a rate equal to the national average for Thailand (Shrestha et al. 2008). However, 32 percent of these connections were reported to be “unofficial” (Shrestha et al. 2008).

While urban access data at the national level and for specific cities may be discordant in some cases, we do not know the extent of this issue. It would be inaccurate to extrapolate from known discrepancies. Indeed, in some cases, the national urban numbers may be close to the level for a capital or largest city. Because there is no universal dataset on electricity access at the city level, we simply use national-level figures for urban areas while acknowledging that this is an imperfect measure.

Looking only at megacities, empirical evidence suggests that grid electricity becomes universally accessible when annual electricity consumption exceeds two megawatt hours (MWh) per capita (Figure 5) (Kennedy et al. 2015). This threshold is not met in Mexico City, Karachi, Delhi, Mumbai, Cairo, Kolkata, and Dhaka, where the percentage of households without access to grid electricity reaches up to 67 percent (Dhaka) (Kennedy et al. 2015). All other megacities in low- and middle-income regions have universal access to electricity, coupled with annual per capita electricity use exceeding 2 MWh (Kennedy et al. 2015). Shenzhen, China, has the highest per capita electricity use of all megacities of these regions; the city’s consumption level is comparable to those observed in the world’s richest cities, such as New York and Tokyo (Kennedy et al. 2015).

Figure 5 | **Cities with Low per Capita Electricity Consumption Rates Generally Do Not Have Universal Access**



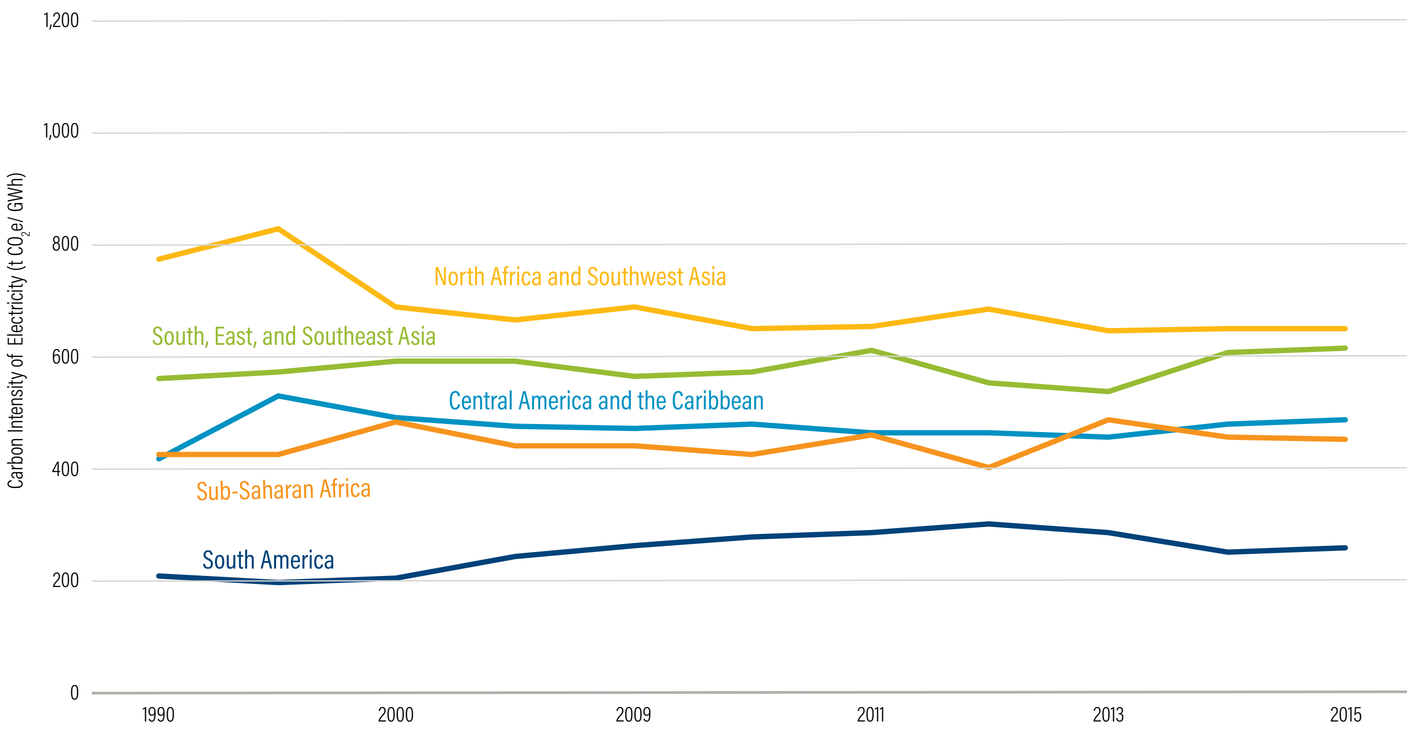
Note: Data from 2011.
Source: Kennedy et al. 2015.

2.2 Carbon Intensity of Electricity at the National Scale: Current Levels and Historical Trends

National values for the carbon intensity of electricity are available from the International Energy Agency's annual report on CO_2 emissions from fuel combustion, which does not account for transnational power grids (IEA 2017). Electricity is generated not only from fossil fuels but also from nuclear, hydropower, geothermal, solar, bioenergy, and other sources. Emissions per GWh therefore vary considerably across years and regions, reflecting national and regional variations in the mix of electricity generation sources.

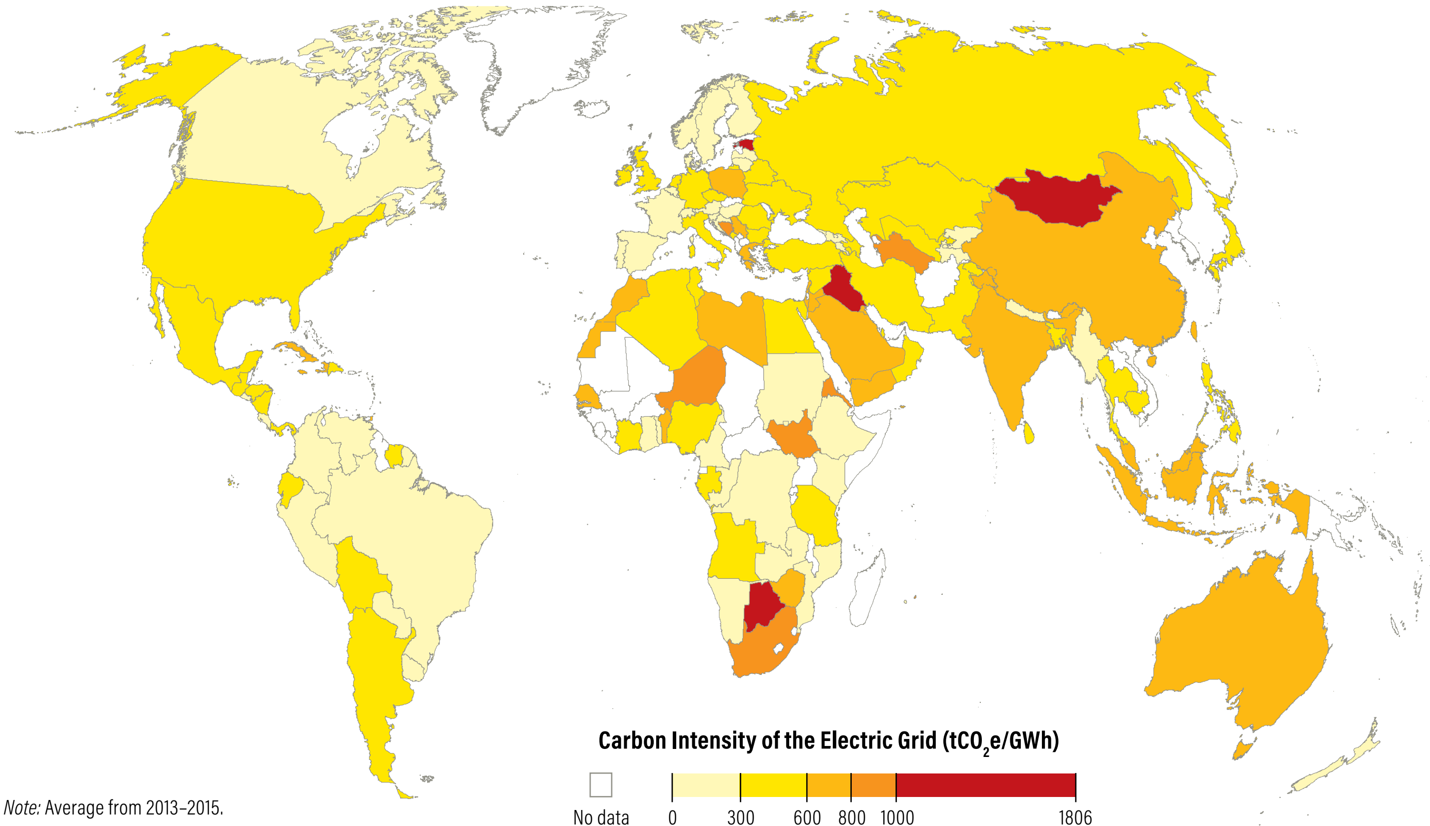
In this analysis, we consider low- and middle-income countries where data exist on urban access to electricity and the carbon intensity of the electricity supply (Appendix B). It would be preferable to use city-level carbon intensities, but the data do not exist outside a small number of cities (mainly megacities) (Kennedy et al. 2015). Hence, we have to assume that the average carbon intensity of a country is a suitable approximation for the carbon intensity of the large cities in the country. Figure 6 shows regional average levels of carbon intensity, which have stayed fairly constant over the last two decades. South America is the only world region in which all countries have remained below the carbon-intensity threshold continuously since 1990 (IEA 2017). Central America and the Caribbean and sub-Saharan Africa have low carbon intensities on average, although there is variation across countries in both regions (Appendix A). Figure 7 shows the average carbon intensity of national electric grids in most countries worldwide. The national electric grids in Europe (Poland is a notable exception), Latin America, North America, and much of sub-Saharan Africa are fairly low carbon, while in some countries, notably China, India, Indonesia, South Africa, and Australia, the electric grids are highly carbon intensive.

Figure 6 | **The Average Carbon Intensity of Electricity Supplies in Most World Regions Has Not Changed Significantly since 1990**



Source: IEA 2017 (carbon intensity data).

Figure 7 | **The National Electric Grids in Europe, Latin America, North America, and Much of Sub-Saharan Africa Are Fairly Low Carbon**



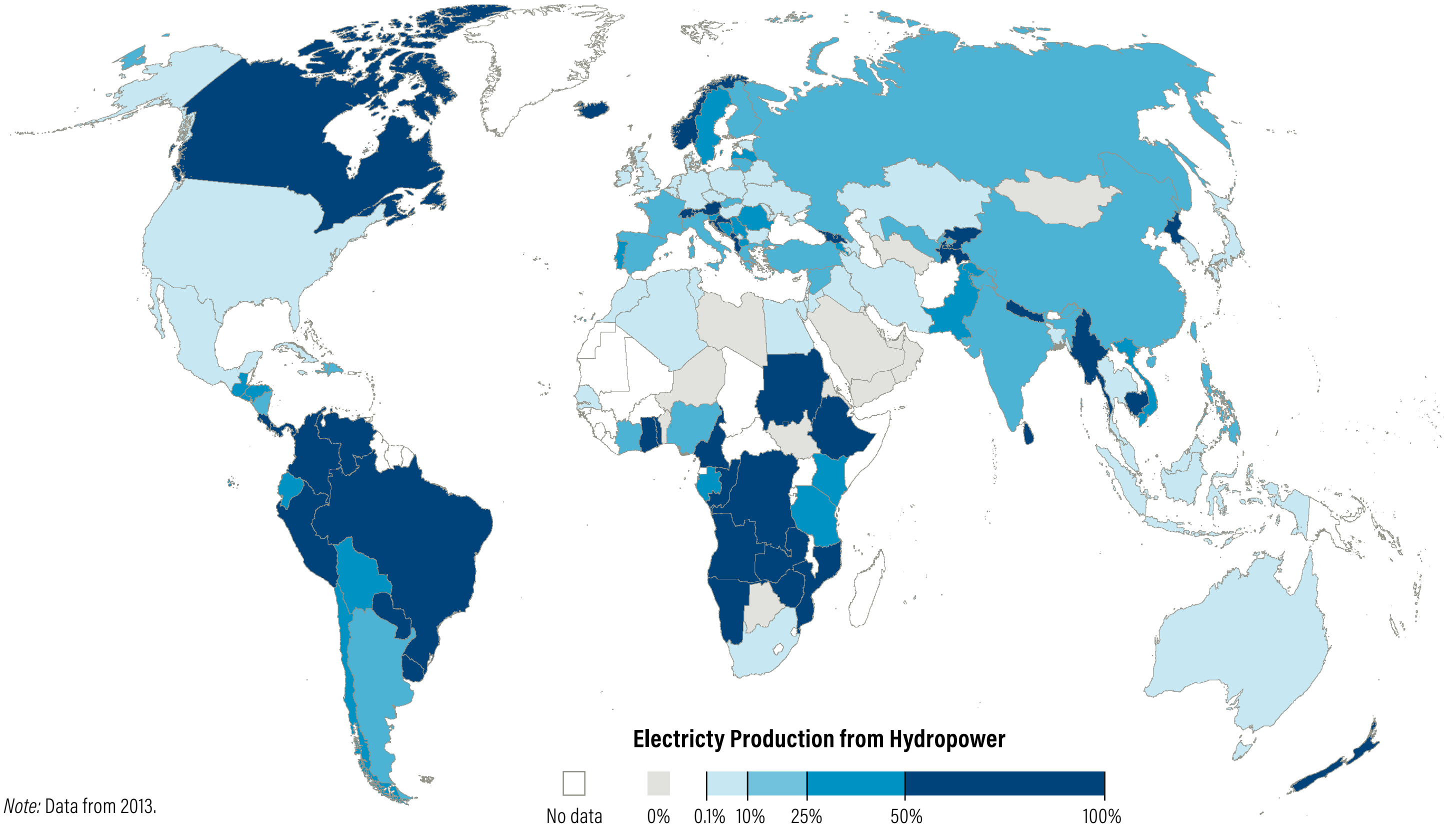
Note: Average from 2013–2015.
Source: IEA 2017.

More detailed national-level data are available. Appendix A provides time series plots of national carbon intensities, highlighting those countries that are currently and historically below (or above) the approximate threshold of 600 tCO_2e/GWh, at which point electrification reduces (or increases) GHG emissions.

One important caveat is that our analysis is based on current levels of carbon intensity of national electricity grids, and any in-depth discussion of the merits of shifting to a more widespread use of electric power will need to take account of future carbon intensities. It is beyond the scope of our analysis to attempt making such a projection for the world. Moreover, national energy sector plans may not accurately reflect future realities. Carbon intensities can fluctuate year by year, due to a suite of factors ranging from changes in fuel prices to hydrologic variability that impacts hydropower production. For example, because of a drought between 2011 and 2014, hydropower generation in Brazil declined 13 percent.[5] During this same period, electricity generation using fossil fuels increased by a dramatic 174 percent.[6]

Many of the countries with low carbon intensity values generate a large proportion of their electricity from hydropower (Figure 8). Climate models and studies indicate much uncertainty as to how global hydropower production will respond to climate change (Turner et al. 2017; van Vliet et al. 2016; Hamududu and Killingtveit 2012). While there is reasonable agreement that climate change will negatively impact hydropower production in certain hotspot regions, such as southern Europe, the southwestern United States, North Africa, and the Middle East, there is less agreement on the implications for China and much of South America and Africa (Turner et al. 2017; van Vliet et al. 2016; Hamududu and Killingtveit 2012; Lehner et al. 2005; Kao et al. 2015).

Figure 8 | **Many Countries with Low-Carbon Electric Grids Generate Most of Their Electricity from Hydropower**



Note: Data from 2013.
Source: World Bank 2017.

2.3 Which Cities Are Candidates for Electrification Today?

We suggest that cities are good candidates to make the transition to low-carbon electric cities when more than 90 percent of their citizens have access to electricity, and their electricity supply has a carbon intensity of less than 600 tCO_2e/GWh.

The rationale for the carbon intensity threshold was explained in Section 1.3 (Box 2). The electricity access threshold of 90 percent is somewhat arbitrary, but we have chosen it to represent the trade-offs that cities in the global South may face when choosing between allocating resources to increasing electricity access or investing in the shift to electric power. While these options are not mutually exclusive, policymakers must consider the opportunity costs of pursuing electrification, given other priorities in cities.

Although many of the data reviewed in this section are from the national level, they can be used to identify cities in the global South that are currently best suited for electrification. We examine 72 countries in the global South in Latin America, sub-Saharan Africa, Middle East/North Africa (MENA), and East, South, and Southeast Asia where data exist on urban electricity access and the carbon intensity of grid electricity. (Appendix B provides additional information on urban electricity access rates and carbon intensity of supply for the three leading cities in the largest and most urbanized countries of the global South). On the basis of our two criteria, we have identified 34 countries in the global South where electrification may be a good strategy. Table 2 provides examples of candidate cities—not an exhaustive list, but mostly the largest or capital cities in the suitable countries—based on the carbon intensity of their national electricity supply and the national urban level of access. Figure 9 maps the location of these same cities.

Table 2 | Tomorrow's Low-Carbon Electric Cities? Candidates for the Transition

	CARBON INTENSITY OF ELECTRICITY SUPPLY (2013–2015 AVERAGE)	
ACCESS OF URBAN POPULATION TO ELECTRICITY (2014)	**Less than 600 tCO_2e/GWh**	**More than 600 tCO_2e/GWh**
More than 90 percent	**Potential electric-city leaders** Accra Addis Ababa Algiers Asunción Bangkok Bogotá Buenos Aires Cairo Caracas Colombo Dhaka Guatemala City Ho Chi Minh City Karachi Kathmandu La Paz Libreville Lima Managua Manila Mexico City Montevideo Panama City Paramaribo Phnom Penh Quito San José (Costa Rica) San Salvador Santiago Santo Domingo São Paulo Tegucigalpa Tehran Tunis **RECOMMENDATIONS:** Cities should aggressively electrify, substituting fossil fuels with electricity while continuing to decarbonize their power supplies.	**High-access polluters** Amman Asmara Baghdad Beirut Casablanca Havana Jakarta Johannesburg Kingston Kuala Lumpur Mumbai Port of Spain Sana'a Shanghai Tripoli Ulaanbaatar **RECOMMENDATIONS:** Cities should prioritize reducing the carbon intensity of their existing power supplies while making sure the enabling conditions are in place for electrification.
Less than 90 percent	**Cleaner, but limited access** Abidjan Brazzaville Dar es Salaam Khartoum Kinshasa Lagos Lomé Luanda Lusaka Maputo Nairobi Windhoek Yangon Yaoundé **RECOMMENDATIONS:** Cities should focus on rapidly increasing power supply from renewable sources and energy efficiency measures and pursue electrification only in communities where high levels of access have been achieved.	**High polluting with limited access** Cotonou Dakar Gaborone Harare Juba Niamey Port-au-Prince Port Louis **RECOMMENDATIONS:** Cities should focus on increasing access and need major investments in renewable power supply before pursuing electrification.

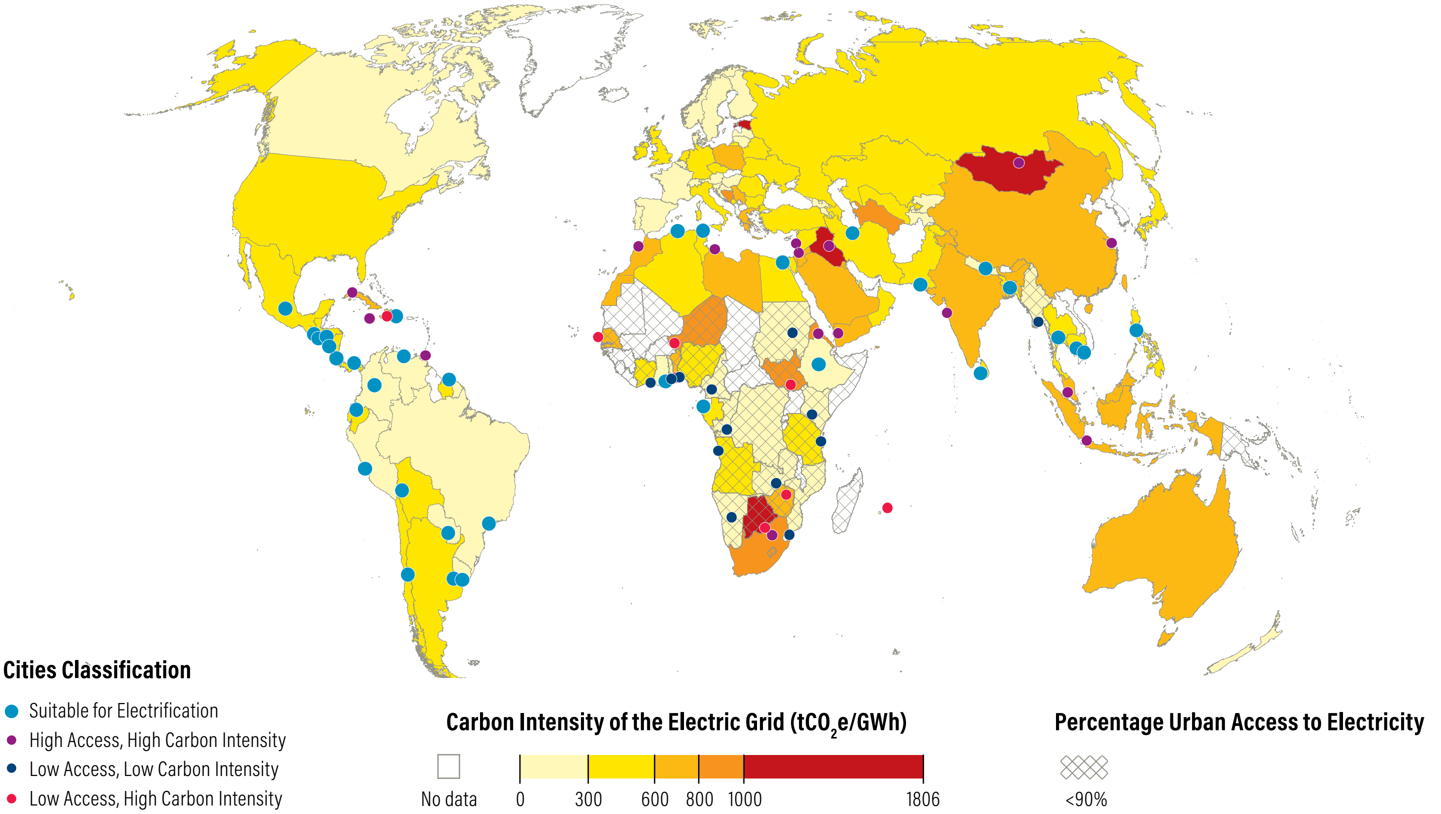
Note: Good candidate cities for electrification have carbon intensities of electricity supply of < 600 tCO2e/GWh and populations where > 90 percent of residents have access to electricity (bold). This is a representative, not exhaustive, set of cities. This list includes the largest or capital city of countries in the global South using our two criteria.
Sources: IEA 2017 (carbon intensity of the electric grid); World Bank 2017 (percentage of the urban population with access to electricity).

In broad terms, electrification is a good strategy to pursue today in all South American cities[7] and in many cities in the Middle East and North Africa region (e.g., Algiers, Cairo, Tehran, Tunis) and Asia (e.g., Bangkok, Dhaka, Ho Chi Minh City, Karachi, Kathmandu, Manila, Phnom Penh). Cities in Ethiopia (Addis Ababa), Gabon (Libreville), and Ghana (Accra) in sub-Saharan Africa also meet the criteria. In total, the 34 countries we've identified contain 105 cities with populations over one million people (UN 2014). In sub-Saharan Africa, only 3 cities out of the 40 with more than one million people would be suitable for electrification (Accra, Addis Ababa, Kumasi) according to our data; in the global South countries in South and East Asia, only 26 out of 202 cities with populations over one million people are good candidates (UN 2014).

Most cities in sub-Saharan African countries have a sufficiently low-carbon electricity supply, but many urban residents remain without access to electricity. On equity grounds, it may be argued that increasing electricity supply (including from renewable sources) and access rates is more pressing today than shifting to more widespread use of electric engines and equipment. This does not mean that electrification is not a good strategy for such cities, but it should be undertaken with greater attention to increasing access and the low-carbon electricity supply. Johannesburg, Havana, Asmara, some cities in the MENA region, as well as a number of cities in China, India, Indonesia, and other countries in Asia are above the threshold of 90 percent access but fail to meet the 600 tCO_2e/GWh carbon intensity threshold. These cities need to develop lower carbon supplies.

A few major cities in the global South (e.g., Cotonou, Benin; Gaborone, Botswana; Port-au-Prince, Haiti; Niamey, Niger; Dakar, Senegal) are found to be unsuitable for electrification on both criteria. Substantial development of low-carbon electricity supplies with a grid connection available to more people is clearly needed in these places before considering electrification.

Figure 9 | **Some Candidate Cities for Electrification, Based on Urban Access to Electricity and the Carbon Intensity of the Electric Grid**



Note: This map is not exhaustive but contains mostly the largest or capital cities in the countries in the global South that fit our two criteria. Electricity access data are from 2014; carbon intensity data are the average of values from 2013 to 15.
Sources: World Bank 2017 (percentage of the urban population with access to electricity); IEA 2017 (carbon intensity of the electric grid).

2.4 Potential Impacts of Electrification on Electricity Demand

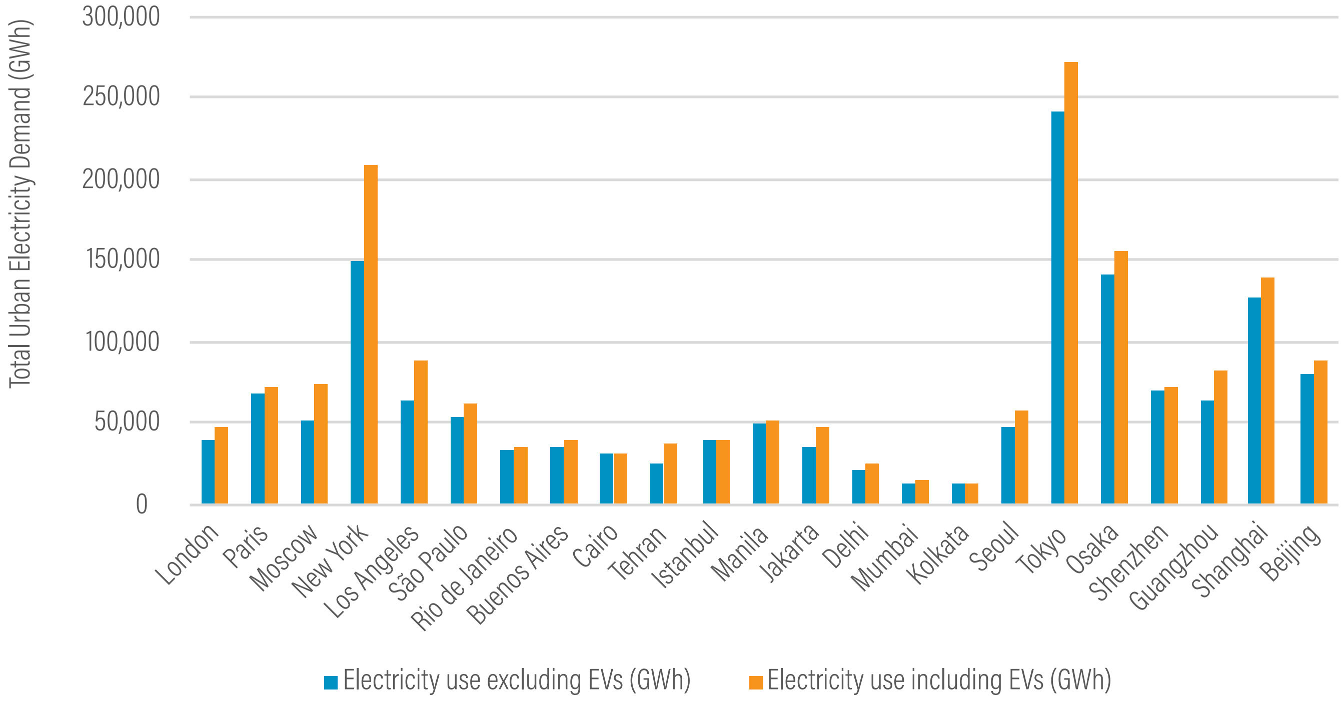
If a city pursues the strategy of shifting from fossil fuel–based to electric power, electricity demand will increase. This can be countered to some degree by implementing energy efficiency measures for electric motors, equipment, and other devices.

Figure 10 illustrates this potential impact by showing rough estimates of the increases in electricity use that would result from a specific change; namely, replacing gasoline vehicles with electric vehicles in megacities. The increases assume no change in transport demand. The figure shows the estimated increases in total electricity demand in 23 megacities that would have occurred for year 2011 if all gasoline vehicles had been replaced with electric vehicles.[8]

The megacities with the greatest projected percentage increases in electricity demand occur both in the global North (New York, Los Angeles, and Moscow) and global South (Tehran, Jakarta, and Guangzhou). In other cities, however, the increases are modest; for example in Rio de Janeiro, Cairo, Manila, Mumbai, and Kolkata. The average increase in urban electricity demand that follows from electrification of the gasoline vehicle fleet is 18 percent.[9] This is a relatively modest average increase, explained in part by the fact that electric motors are about four times more efficient than internal combustion engines (Gilbert and Perl 2013).

The wide variation in demand increases is the result of differences in the size and wealth of cities, the extent of vehicle ownership and use, and the prevalence of gasoline as a fuel (for example, many automobiles in Europe run on diesel). These calculations can be considered only as indicative estimates of the impact of electrification on electricity demand; the actual changes in demand will depend on the specific characteristics of electric vehicle fleets as they are rolled out in cities.

Figure 10 | **Urban Electricity Demand Would Rise If Gasoline Vehicles Were Replaced with Electric Vehicles**



Note: Data from 2011. Estimated impacts assume that 9.09 megajoules of electricity is required to displace one liter of gasoline (Hawkins et al. 2013).
Sources: Authors' analysis based on energy data from Kennedy et al. (2015) and vehicle characteristics assumed by Hawkins et al.

3. TRANSITIONING TO LOW-CARBON ELECTRIC CITIES: POLICY, INSTITUTIONAL, AND GOVERNANCE ENABLERS AND BARRIERS

The policy, institutional, and governance barriers and enablers for electric cities can be classified broadly as "economic" and "noneconomic." Chief among the economic barriers is the upfront investment cost of infrastructure and technology associated with low-carbon electricity generation and electric devices.

In this section, we examine the literature to assess the cost of measures that would likely be required as part of the transition to low-carbon electric cities. We do not make recommendations on what specific technologies should be prioritized within the three broader areas of technological change; this is beyond the scope of our analysis. Specific technology choices will be city-specific, based on the city's development and geographical context, current technology baseline and costs of energy-efficient or electric alternatives, the building stock, the electricity mix of the grid, and the current price of electricity and fossil fuels, among other factors.

After reviewing costs of low-carbon power generation (Section 3.1) and electrification (Section 3.2), we discuss the broader economic (Section 3.3) and noneconomic (Section 3.4) barriers and enablers.

3.1 Costs of Low-Carbon Power Generation

The past decade has witnessed a dramatic decline in the cost of renewable energy, which is increasingly becoming competitive with fossil fuel generation. Between 2009 and 2014, the cost of solar photovoltaic (PV) modules declined by 75 percent, while the cost of wind turbines declined by almost one-third (IRENA 2014). Between the last quarter of 2015 and a year later, average PV module prices fell by another third (REN21 2017). Between 2010 and 2016, the global weighted average levelized cost of electricity (LCOE) for utility-scale solar PV projects fell by 67 percent, with an average LCOE of $120/MWh in 2016 (REN21 2017). Likewise, the global weighted average LCOE of onshore wind power dropped 19 percent over the same period, and the LCOE for the average wind farm commissioned in 2016 was $70/MWh (REN21 2017). These costs are comparable with those of fossil fuel–generated electricity, which has LCOE values of between $45/MWh and $140/MWh (REN21 2017). The cost of residential solar PV has also been declining significantly in recent years. The average LCOE in 2016 was $80/MWh in India and $110/MWh in China, making solar PV competitive with natural gas in India and nearly so in China, although the costs of battery storage are not included (IRENA 2016; BNEF 2016).

In the global South, only a limited number of studies have compared renewable energy with conventional fossil fuel–fired generation at the city level. In Palembang, Indonesia, an analysis of low-carbon energy alternatives concluded that geothermal was the most cost-effective option to meet the modern demands of the power sector. The installation of 1,000 MW of geothermal power and upgrading natural gas–fired power plants with the best available technology would require an investment of $2.9 billion; however, it would also result in annual savings of $175 million, thereby paying back the investment in 15 years (Colenbrander et al. 2015). The shift would reduce CO_2 emissions from the state grid by 12.2 percent in 2025, relative to business-as-usual trends (Colenbrander et al. 2015). Many cities in the global South rely on diesel generation, especially for backup power. In Nigeria, power load shedding is widely practiced in urban areas, with most cities experiencing several days without power per week (Okoye et al. 2016). Diesel generators are necessary to reduce the gap between energy demand and supply, but they are not economically or environmentally justifiable due to rising fuel prices, GHG emissions, and local air and noise pollution. Okoye et al. (2016) compared the costs of stand-alone, off-grid PV systems in Nigerian cities (Lagos, Kano, and Onitsha) with those of diesel generation. They determined that the LCOE of the PV systems ranged from 0.2 to 0.5 $/kWh, including battery costs, which is lower than the cost of diesel generation (Okoye et al. 2016). The LCOE values for stand-alone PV systems in urban Nigeria could be lowered further, to the point of grid parity, if the Nigerian government offered rebates for PV deployment (Okoye et al. 2016).

The urban population of Somaliland also relies almost entirely on diesel generators. An analysis of a hybrid PV-wind-diesel system in the state's largest city, Hargeisa, found the cost of energy to be 70 percent less than that of a diesel-only system, with operating costs reduced by 43 percent (Abdilahi et al. 2014). Capital costs, however, increased 634 percent above the business-as-usual case, leading Abdilahi et al. (2014) to conclude that the most practical solution to reduce diesel dependence in Hargeisa is an electricity mix of about 2 percent solar PV, 56 percent wind turbine, and 43 percent diesel generators. Likewise, in Johor Bahru, Malaysia, a PV-wind-diesel hybrid system was the most favorable solution to relieve diesel dependence, resulting in only modest increases in the cost of energy, but reducing CO_2 emissions by 30 percent (Ngan and Tan 2012).

3.2 Costs of Electrification

Vehicles

ELECTRIC BUSES

Two studies in India and China indicate that electric buses are not yet competitive with diesel buses, given investment costs and current prices. In Bengaluru, India, while electric buses were estimated to generate greater profits per day ($170 vs. $93) on a per kilometer (km) basis, the price of an electric bus is about three and a half times that of a diesel bus, leading to a payback period of eight years compared with four years for a diesel bus (Adheesh et al. 2016). In Shenzhen and Zhengzhou, China, the investment cost of electric buses was calculated to be double that of diesel buses, resulting in an annualized cost per kilometer of $1.12 vs. $0.83 (Grütter 2015). In addition, India and China still rely heavily on coal-based power, which reduces the CO_2 abatement benefits of shifting to electric buses.

Mahmoud et al. (2016) reviewed the costs of three technologies for electric buses: hybrid, battery, and fuel cell. Electric buses are significantly more expensive to manufacture than diesel buses (nearly double the unit price) due to the high cost of electric components. On the operational side, however, battery electric buses are 80 percent cheaper than diesel (0.15 vs. 0.8 $/km) (Mahmoud et al. 2016). Infrastructure and maintenance costs associated with each bus type were factored in to calculate a total cost of ownership that ranged from 2.61 $/km for diesel buses to 6.83 $/km for battery electric buses (Mahmoud et al. 2016). These costs assumed a 12-year lifetime and 60,000-km annual driving distance for both types of bus (Mahmoud et al. 2016). Ownership costs for electric buses are highly sensitive to the costs of electric components and to how much the bus service is used. However, by 2030, ownership costs for electric buses are expected to drop by 30–50 percent and, with high to moderate usage levels, the electric buses will be competitive with diesel and compressed natural gas models (Mahmoud et al. 2016).

ELECTRIC RICKSHAWS

In India's congested urban areas, LPG- and diesel-powered auto-rickshaws play important roles in public transportation, but the latter are neither cost-efficient nor environmentally benign. The potential for electric rickshaws to help mitigate environmental and transportation problems has been limited due to the high costs of imported batteries (Rajvanshi 2002). However, a recent analysis of e-rickshaws in West Bengal, where the electric three-wheelers are now operational in many urban and suburban areas, has concluded that LPG-powered rickshaws are much less efficient than their electric counterparts, requiring about an extra 300 kilojoules and 0.5 Indian rupees (Rs) per passenger-kilometer to operate (Majumdar and Jash 2015). Environmentally, LPG-powered rickshaws emit an additional five grams of carbon dioxide per passenger-kilometer (Majumdar and Jash 2015).

These results were tempered by the fact that e-rickshaws still face major hurdles to widespread use in Indian cities. They have slow travel speeds, limited motor and battery capacity (meaning shorter travel ranges), and high purchase costs. An e-rickshaw costs, on average, $1,700 in West Bengal, whereas the average rickshaw driver earns about $9 per day (Majumdar and Jash 2015). The reduced travel speed and range of e-rickshaws could possibly worsen the existing congestion in Indian cities. Furthermore, there is the problem of the "dirty" grid in West Bengal. Electricity is supplied almost entirely from coal-fired thermal plants, meaning that e-rickshaws charged from the grid will not help abate CO_2 and pollutant emissions at the state level, although air quality will improve at the local level.

ELECTRIC VEHICLES

Electric vehicles have seen significant cost reductions in recent years due in large part to steep declines in the cost of batteries, which accounted for one-third of the cost of electric vehicles in 2016 (Randall 2016). Costs declined by approximately 14 percent annually between 2007 and 2014 and fell 35 percent in 2015 (Nykvist and Nilsson 2015; Randall 2016). Given that, the EVs will become cost competitive when battery costs are about $150 kWh (Nykvist and Nilsson 2015). Bloomberg New Energy Finance projects that EVs will be cost competitive with internal combustion engines by 2022 (Randall 2016).

A study by the Grantham Institute for Imperial College London and the Carbon Tracker Initiative estimates that EVs will achieve cost parity with internal combustion engines by 2020 and that EVs (battery electric and hybrid) will comprise 19 to 21 percent of the market share of road transport over the subsequent 10 years (Sussams and Leaton 2017). This finding holds across a variety of climate policy scenarios (Sussams and Leaton 2017). Other studies generally are in accord with this timeframe, but the cost break-even point also depends on such factors as the price of oil, the existence of carbon pricing, vehicle size, and the average annual driving distance (Wu et al. 2015; Newbery and Strbac 2016).

South America is better positioned for vehicle electrification than many regions because of the dominance of hydropower in its energy mix (see Section 2.2). Paraguay and Bolivia, the two poorest nations in South America, are potentially good candidates for scaling up battery-powered electric vehicles, given the low-carbon power supplies in these countries (Sauer et al. 2015). Assessing several scenarios for market penetration of EVs in Bolivia and Paraguay, Sauer et al. (2015) calculated that replacing the existing fleet of diesel-powered light vehicles in each country with 40,000 EVs per year for 10 years would bring cumulative direct economic benefits of $996 million to Paraguay and $1.4 billion to Bolivia (Sauer et al. 2015).

Lighting

Other strategies to electrify fossil fuel–based services have targeted the informal economy. In India, many workers in the informal sector suffer widespread energy poverty, with virtually no access to grid electricity. Among India's 10 million street vendors, poor lighting in nighttime markets is the industry's greatest energy constraint (Yaqoot et al. 2014; Szakonyi and Urpelainen 2015). The solar lantern is one solution. Although often seen as aiding development in rural areas, solar lanterns in cities are a basic form of electrification to replace kerosene or other fossil fuel–powered lanterns (Yaqoot et al. 2014). One study of 1,300 vendors in the city of Dehradun, India, has concluded that entrepreneurs who service 100 solar lanterns with a rental scheme and central charging station could meet the lighting needs of street vendors at a rental price that is lower than they are willing to pay, and higher than required to cover the operating costs of the charging station (Yaqoot et al. 2014).

Furthermore, a shift to solar lanterns would lead to significant savings for both the Indian government—because kerosene is currently highly subsidized—and for individual households. In Uttarakhand State, without government support, such a shift would result in savings to households of about Rs 7,000 (about $400 in purchasing power parity) over the 20-year lifespan of a lantern compared with kerosene lighting (Yaqoot et al. 2014). While solar lantern systems provide basic lighting, they do not help the urban underserved with their productive needs, such as operating small machines and devices. However, solar PV systems larger than 100 watts can support productive uses as well as task lighting, and community-owned, community-shared systems would be options even where individuals do not have adequate rooftop space (Westphal et al. 2017).

Cooking

As discussed, the use of solid, unprocessed cooking fuel remains pervasive among the urban populations of sub-Saharan African and other low-income countries. Clean cooking solutions include the use of electricity. The high cost of electric stoves remains a barrier for the urban poor. In sub-Saharan Africa, the price of an electric cookstove in 2012, for example, ranged from $15–$50 for a single burner stove, $40–$150 for a double burner, and more than $150 for an electric induction stove (Kammila et al. 2014). While these costs are somewhat comparable to those of LPG stoves, basic biomass stoves cost less than $15 (Kammila et al. 2014).

If the environmental costs are included in the full life cycle costs of stoves, then the picture changes completely. In Ghana, electric stoves have higher life cycle costs than wood or charcoal, but when the annual environmental costs of emissions from charcoal and wood are factored in, electric stoves are much more economical (Afrane and Ntiamoah 2012).

3.3 Other Economic Barriers and Enablers

Fossil fuels are often highly subsidized, creating “headwinds” for the development of renewable energy. The International Energy Agency has estimated that fossil fuel consumption subsidies totaled $548 billion across 40 developing countries and emerging economies in 2013, compared with $121 billion in subsidies for renewable energy (IEA 2012). The International Monetary Fund has calculated that post-tax, fossil fuel subsidies totaled $5.3 trillion in 2015, including the externalities associated with fossil fuel consumption, such as local air pollution (Coady et al. 2015). The Global Subsidies Initiative has previously estimated that renewable energy subsidies were between 1.7¢ and 15.4¢ per kWh in 2011, while fossil fuel subsidies were in the range of 0.1¢ to 0.7¢ per kWh; however, the social costs of fossil fuels could add as much as 23.8¢ per kWh (Kitson et al. 2011). Public policy–makers need to factor in these social costs when making decisions about energy supply. Ultimately, we need fossil fuel subsidy reform and a universal price on carbon. While political economy issues exist, such as regulatory capture by fossil fuel interests, there is momentum on carbon pricing, with about 40 nations and over 20 cities, states, and regions and about 40 subnational jurisdictions already putting a price on carbon as of 2016 (Zechter et al. 2016).

Fiscal and regulatory policies, such as feed-in tariffs, net or gross metering, quotas, tendering, and renewable portfolio standards are needed to create a more level playing field for renewable energy (REN21 2017). Such policies may be necessary to enable the market introduction of renewable energy technologies, foster development of infrastructure and supply chains, and stimulate further deployment of clean energy, particularly in the absence of carbon pricing in most places (Angelou et al. 2013). These fiscal and regulatory policies need to be stable and consistent to foster private sector investment (Westphal and Thwaites 2016). In this way, the problem of high costs is tied directly to market conditions. Policy enablers for low-carbon electric cities, such as direct and indirect government subsidies and stable tariff regulations, can ensure competitive energy supplies to low-income regions. In urban centers of Pakistan, such as Quetta and Multan, government incentives like tariffs and subsidies are essential for making green energy projects viable, and to equalize the costs of PV- and grid-supported electricity (Khalid and Junaidi 2013; Sadati et al. 2015). While Pakistan’s government generously subsidizes nonrenewable energy, no comparable aid is given to renewable technologies or equipment. Such technologies must be imported to Pakistan and require high investment costs relative to their capacities and efficiencies (Ali et al. 2015).

3.4 Institutional and Governance Barriers and Enablers

Numerous noneconomic barriers inhibit the three main technological developments—shifting from fossil fuels to electric power, using low-carbon electricity, and implementing energy efficiency—that enable the transition to low-carbon electric cities. Prime among them are ineffective government institutions, policies, and legislation, which too often lack transparency and continuity. Inadequately resourced implementing agencies lack clear administrative responsibilities and permitting procedures. Energy systems are often inflexible and unable to absorb and integrate new technologies. Incumbent technologies are supported and innovative technologies may be blocked by powerful vested interests. In addition, human factors such as low awareness, expertise, and training in renewable technologies, and behavioral resistance to change, also represent significant obstacles (Angelou et al. 2013; Garg et al. 2014; Okoye et al. 2016; World Bank 2015b; Yadoo and Cruickshank 2012).

Cities may also face specific barriers in terms of their relations with state and national governments. In Delhi, for example, the principal barrier to increasing electricity access and integrating electricity policies is the political disconnect between state and municipal authorities. The state is responsible for planning and delivering energy services and the municipality for alleviating poverty (Dhingra et al. 2008). The separation between these services means that no single authoritative body exists to plan, deliver, and monitor energy supplies at the municipal level. Local and national governments will need to draft new policies, targets, and support mechanisms to overcome barriers and enable more efficient development and deployment of low-carbon technologies. A predictable renewable energy policy framework should be developed and integrated into an overall energy strategy that has clear targets, offers technological and market-based incentives, and is responsive to national and global market trends (Angelou et al. 2013). Local-level planning is necessary, even if electricity planning is initiated at the national level. The adoption of local-level policies to promote clean energy is becoming more prevalent in developing countries (REN21 2017).

Other enablers of low-carbon energy include robust financial sectors, investment in research and development, strong commitments from political leaders, and legal and regulatory frameworks to promote business and investment opportunities in the private sector (Angelou et al. 2013). Community engagement is vital. In Kenya and Nepal, recent laws have been passed to remove restrictions on electricity that is generated and distributed independently of national utilities (Yadoo and Cruickshank 2012). This new independence allows communities and local developers to connect micro-grids to national networks. To further enable low-carbon electricity in these regions, training centers for renewable energy mini-grids are needed to deliver technical, administrative, and negotiating skills to the local population.

4. CONCLUSION

The development of low-carbon electric cities is an essential strategy for reducing global greenhouse gas emissions and has the potential to provide many benefits to the urban underserved, including increased access to energy; reduced energy bills; and improved economic productivity, comfort, health (reduced illnesses), and climate change resilience.

The transition to low-carbon electric cities has three core elements: replacing fossil fuel–powered engines, furnaces, and other equipment with electric devices (called electrification in this paper); generating electricity from renewable or fossil fuel–free sources, including distributed renewable energy systems, both outside and within the city boundaries; and implementing energy efficiency measures, to provide comparable or higher levels of service with lower energy input.

All cities should seek to use electricity from fossil fuel–free sources, and constantly aim to improve energy efficiency. The first element of the strategy—electrification—however, should be a lower priority until cities have sufficiently high access to low-carbon-intensity electricity.

In this paper, we identify cities that are suitable for electrification today on the basis of two thresholds: access to electricity use must be greater than 90 percent, and the carbon intensity of electricity must be less than 600 tCO_2e/GWh. By grouping cities on the basis of these thresholds, we not only identify good candidates for radical electrification today, we show which cities need urgent attention to electricity access—and those that have largely tackled access, but have unsustainable, high-carbon power systems that urgently need to be decreased in carbon intensity.Potential electric-city leaders, which pass both thresholds, include all South American cities, many cities in the Middle East/North Africa region (e.g., Algiers, Cairo, Tehran, Tunis), and a few in Asia (e.g., Bangkok, Ho Chi Minh City, Kathmandu, Manila) and sub-Saharan Africa (e.g., Accra, Addis Ababa, Libreville).

A second group of cities are the high-access polluters. This group includes many cities in China, India, and South Africa, for example, where greater attention should be given to reducing the carbon intensity of electricity grids while the enabling conditions for electrification are established.

The third category of cities are cleaner, but have limited access, with carbon intensities below 600 tCO_2e/GWh but access to electricity under 90 percent. Such cities are particularly prevalent in sub-Saharan Africa. The highest priority for these cities is providing access to electricity. Cities that are high polluting with limited access are less common. Our study identified a few of these cities, which require major investments in renewable power supply before pursuing electrification.

In some countries in which we argue that electrification makes sense, we see some promising signs of a transition. Most deployment of battery electric buses is in North America, Europe, and China, but six cities in Brazil (Belo Horizonte, Campinas, Curitiba, Porto Alegre, Rio de Janeiro, and São Paulo) either have battery electric buses in operation or have started pilot programs (Li 2017). While shifting from fossil fuel use to electric power can bring benefits to the underserved, there may be trade-offs, and the specific context matters. The use of electric stoves may not be the best use of resources if the underserved population of a city lacks access to an affordable and reliable supply of electricity. Electrification of transport would also improve local air quality in the city,[10] but the electrification of a municipal bus fleet may not be a good mobility solution for the underserved if the bus lines do not serve their areas or are too expensive. But some solutions, such as distributed renewables, could both provide access to clean, reliable, and affordable electricity and allow a shift from fossil fuel–burning devices, such as kerosene lighting.

A range of policy initiatives can help with the development of low-carbon electric cities. The upfront investment cost of infrastructure and technology associated with low-carbon electricity generation and electric devices remains perhaps the biggest barrier impeding the transition to low-carbon electric cities. Broadly, the production and use of electric devices needs to be incentivized—for example, through subsidies for electric rickshaws, buses, and cars or electric stoves, LEDs, and solar lanterns, and through provision of charging infrastructure. Other steps include updating procurement processes that mandate zero-emission vehicles in municipal fleets, blending public and private finance to address risk perceptions, and encouraging manufacturers to develop new models of engagement, such as battery leasing (Maassen and Castellanos 2017). Grid infrastructure will need to be upgraded in many cases to deal with additional loads. Legal and regulatory environments need to broadly support the electrification process, for example, by changing building codes and practices to foster the use of heat pumps in buildings. Low-carbon electricity needs to be made cost-competitive by removing fossil fuel subsidies and adopting carbon pricing. Fiscal and regulatory policies, such as feed-in tariffs, net or gross metering, quotas, renewable portfolio standards, and tendering, are important to effectively incentivize renewable electricity generation where there has been a failure to incorporate the external social costs of fossil fuel–generated electricity.

Cities with highly carbon-intensive electricity supplies (> 600 tCO_2e/GWh) need to focus on transitioning to low-carbon electricity generation, while establishing the enabling conditions for substantial electrification. Cities with low electricity access should first focus on ameliorating this situation through programs that specifically target the underserved and address the institutional, political, and cost barriers. These include policy incoherence between state and federal governments, inadequate utility and municipal service to informal settlements, and high costs of traditional grid connections. Possible solutions include, for example, electricity levies and financial models, such as pay-as-you-go schemes, that incentivize distributed renewable energy within the city.

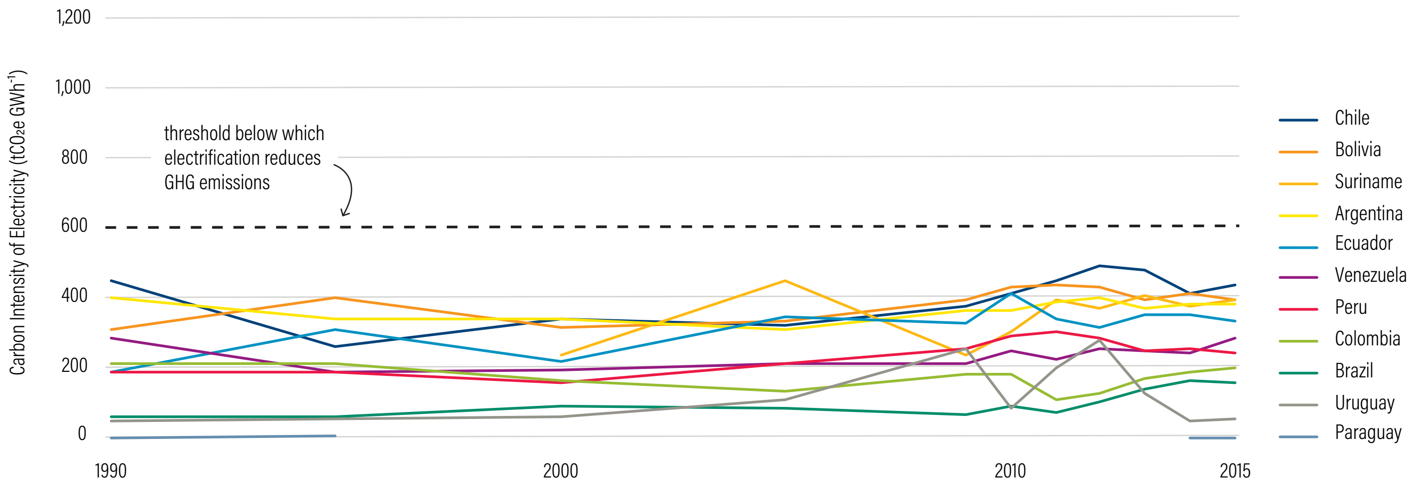
APPENDIX A. CARBON INTENSITY OF ELECTRICITY SUPPLIES AT THE NATIONAL LEVEL ACROSS WORLD REGIONS

Latin America

In 2015, Chile—with considerably more coal in its power-generating mix than all other South American countries—was still far below the threshold range at around 450 tCO_2e/GWh. Paraguay, Uruguay, Brazil, and Colombia have consistently had the lowest carbon intensities in the region, all with more than 50 percent of electricity supplied from hydropower, including 100 percent in Paraguay (Figure A-1) (IEA 2017). Hydro and natural gas dominate the electricity mixes in all other South American countries.

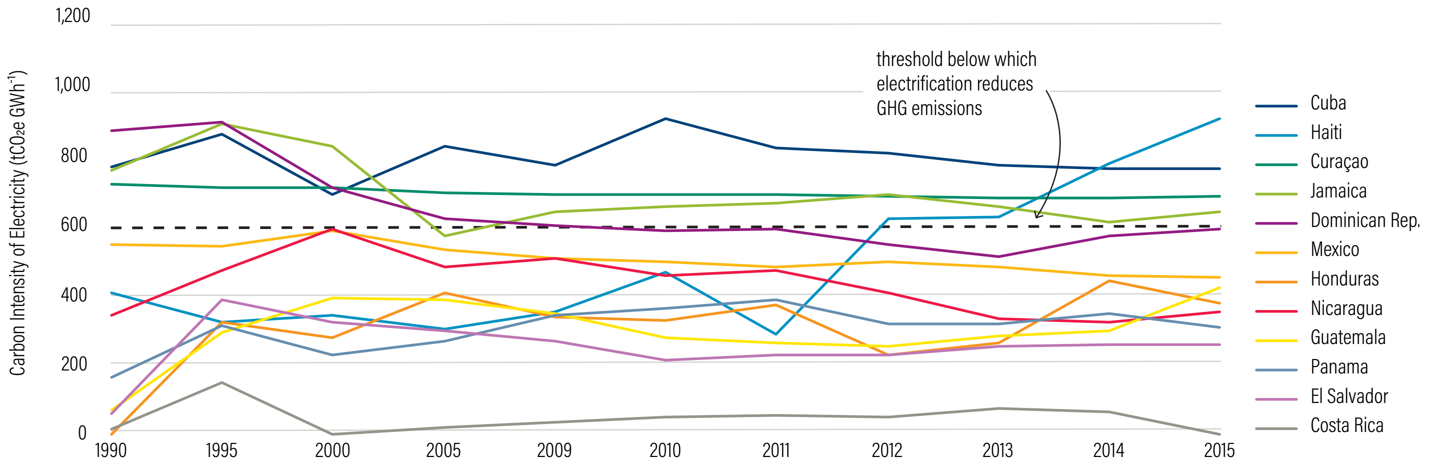
In Central America and the Caribbean, most countries sit at or below the threshold range, with only Cuba and Haiti consistently above 700 tCO_2e/GWh (96 percent of Cuba's electricity is fossil fuel based, mostly from oil) (Figure A-2) (IEA 2017). On average, carbon intensities in the Caribbean (e.g., Haiti, Curaçao, Jamaica, Trinidad and Tobago, and the Dominican Republic) are higher than those in Mexico and Central America, although in the past decade these have dropped below 700 tCO_2e/GWh in the latter four countries (IEA 2017). In Central America, Costa Rica has the lowest values in the region. Like the aforementioned countries in South America, but unlike Central America and the Caribbean, power in Costa Rica is sourced primarily from hydropower, with only 12 percent from fossil fuels (IEA 2017).

Figure A-1 | **Carbon Intensity of Electricity Supplies at National Level in South America, 1990–2015**



Source: IEA 2017.

Figure A-2 | **Carbon Intensity of Electricity Supplies at National Level in Central America and the Caribbean, 1990–2015**



Source: IEA 2017.

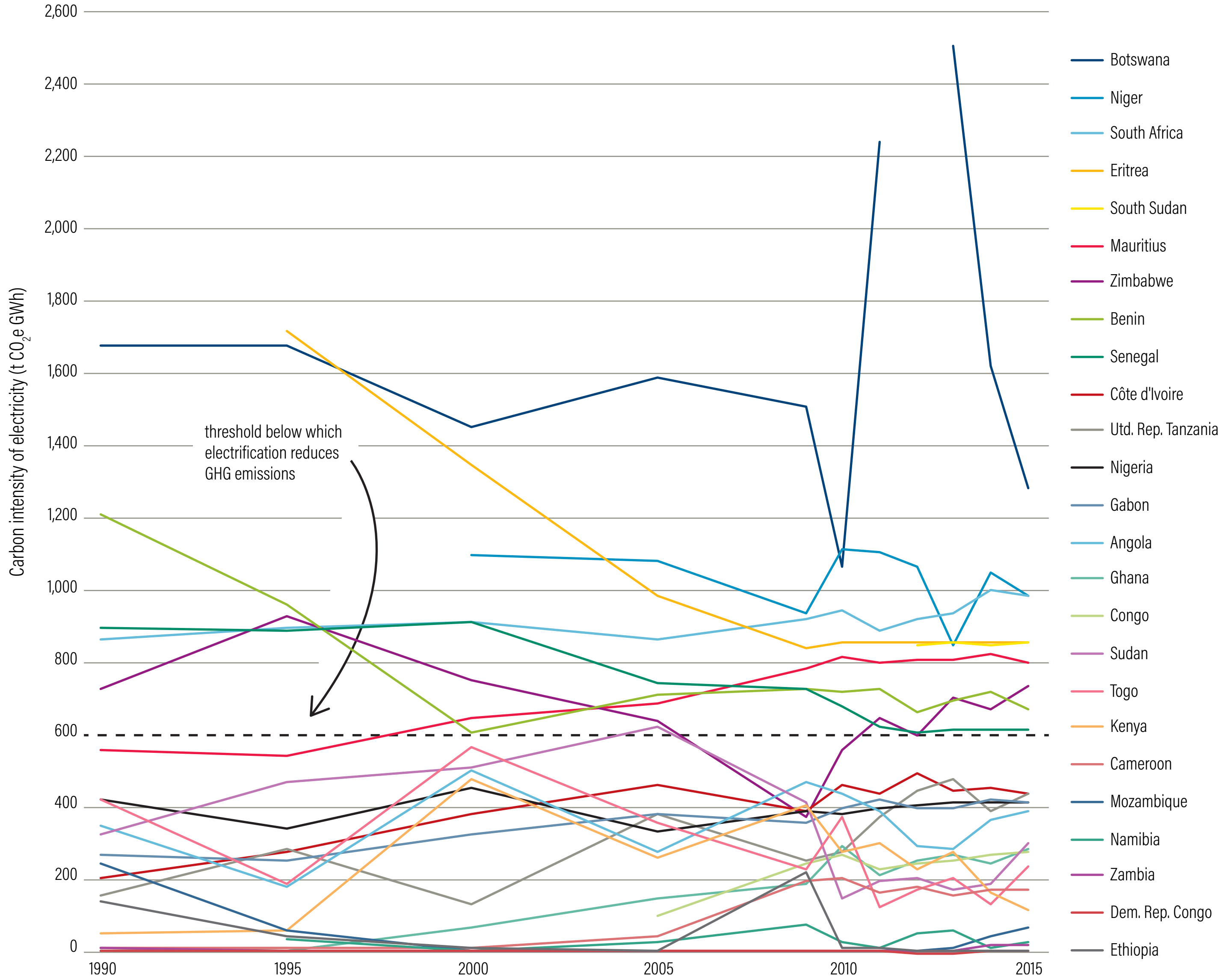
Sub-Saharan Africa

In sub-Saharan Africa, Botswana, Niger, South Africa, Eritrea, South Sudan, Mauritius, Zimbabwe, Benin, and Senegal were above the threshold during 2013–15. (Figure A-3) (IEA 2017). All other sub-Saharan countries lie below 500 tCO_2e/GWh. Namibia, Mozambique, the Democratic Republic of the Congo, Zambia, Ethiopia, and the Republic of the Congo all have carbon intensities of less than 100 tCO_2e/GWh, and all these countries get a substantial portion of their electricity from hydropower (IEA 2017).

North Africa and Asia

Current and historical levels of carbon intensity in North Africa and Southwest Asia are higher than in sub-Saharan African countries and, on average, highest among all continental regions considered here (Figure A-4). Except for Algeria, Egypt, Iran, and Tunisia (all countries use natural gas–based electricity), all nations in North Africa and Southwest Asia are above 600 tCO_2e/GWh (IEA 2017). Between 2005 and 2015, Iraq's carbon intensity increased sharply from ~800 tCO_2e/GWh to more than 1,100 tCO_2e/GWh in

Figure A-3 | **Carbon Intensity of Electricity Supplies at National Level for Sub-Saharan Africa, 1990–2015**

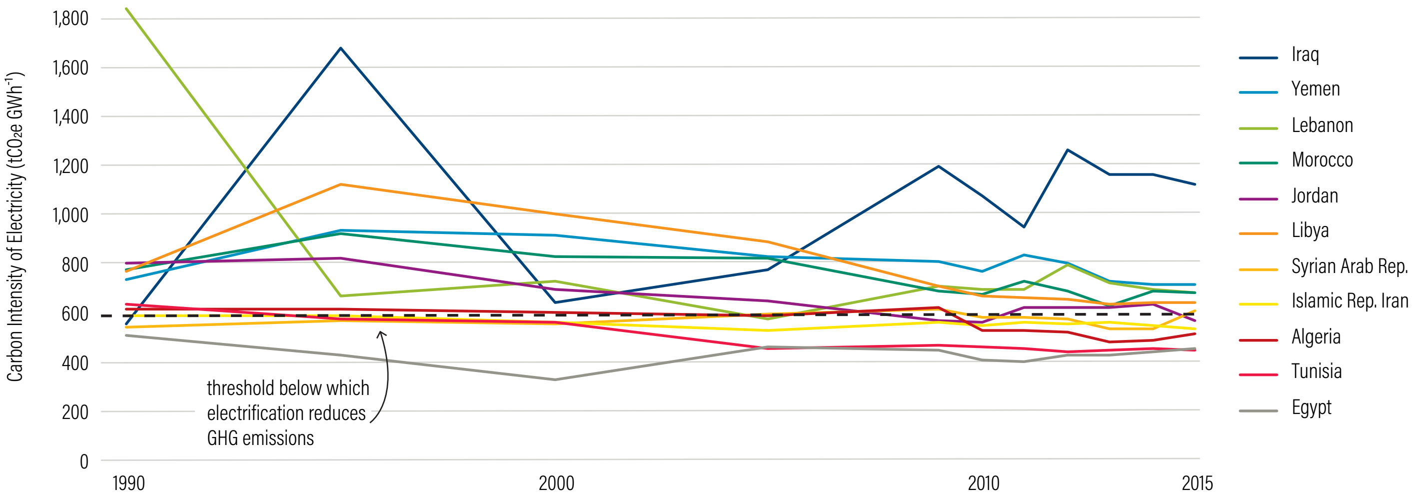


Source: IEA 2017.

2015 (IEA 2017). More than 90 percent of Iraq's electricity output is from fossil fuels (IEA 2017). Libya is notable for a different trend, with its carbon intensity declining steadily from about 1,100 tCO_2e/GWh in 1995 to ~650 tCO_2e/GWh in 2015 (but still with 100 percent of electricity from fossil fuels) (IEA 2017). This can be understood partly as a major shift in electricity carriers, from entirely oil in the early 1990s to mostly natural gas in recent years (IEA 2017).

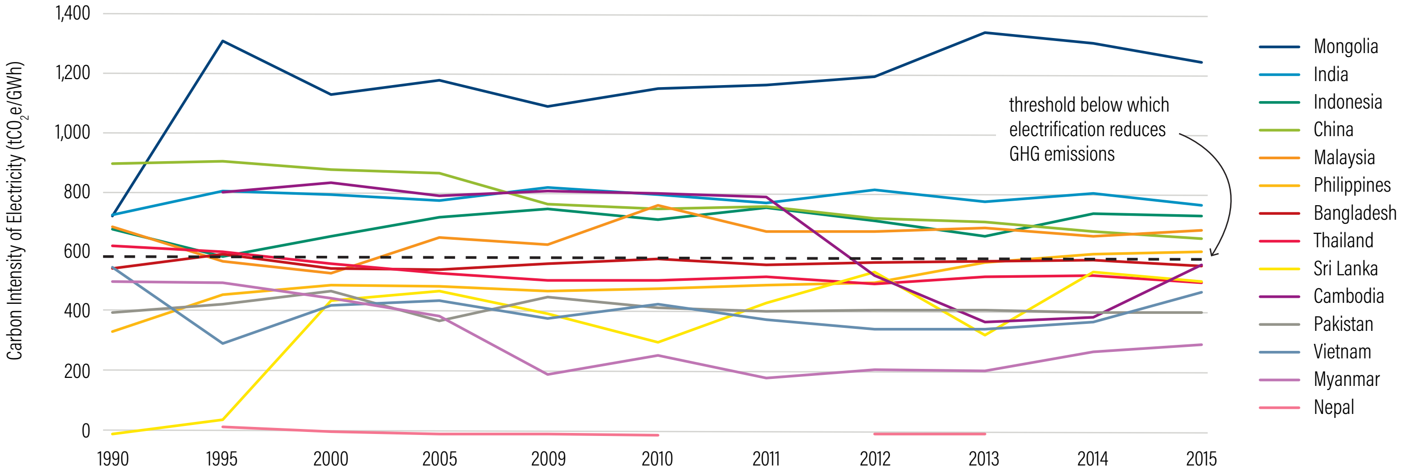
In South, East, and Southeast Asia, Mongolia, India, Indonesia, China, and Malaysia all had carbon intensities that exceeded 600 tCO_2e/GWh in 2013 (Figure A-4) (IEA 2017). Mongolia stands out with a very high carbon intensity of ~1,250 tCO_2e/GWh in 2015 (IEA 2017). Sri Lanka is also notable: its carbon intensity rose sharply from ~0 tCO_2e/GWh in 1990 to more than 400 tCO_2e/GWh in 2015, coincident with increased electricity generation from fossil fuels (rising from 0 to 50 percent in 10 years) (IEA 2017). Nepal ranks with Ethiopia and the Democratic Republic of the Congo as having one of the world's least-carbon-intensive electricity supplies, with almost 100 percent of power coming from hydropower (IEA 2017). In Cambodia, the carbon intensity of electricity has historically been around 800 tCO_2e/GWh but, in 2013–15, it was on average ~450 tCO_2e/GWh (IEA 2017). In this period, the share of electricity from fossil fuels decreased from 95 to 42 percent (IEA 2017). In the world's most populous nations—India and China—the carbon intensity of electricity has remained above the threshold since 1990, although China's level has dropped from 875 to ~660 tCO_2e/GWh in the past decade (IEA 2017). In both countries, the share of electricity carried from fossil fuels is 80 percent, most of which comes from coal (IEA 2017).

Figure A-4 | **Carbon Intensity of Electricity Supplies at National Level in North Africa and Southwest Asia, 1990–2015**



Source: IEA 2017.

Figure A-5 | **Carbon Intensity of Electricity Supplies at National Level in South, East, and Southeast Asia, 1990–2015**



Source: IEA 2017.

APPENDIX B. DEMOGRAPHIC AND ELECTRICITY SUPPLY CHARACTERISTICS OF SOME COUNTRIES IN THE GLOBAL SOUTH[11]

Table B-1 | **South America**

COUNTRY[a] (POPULATION)	LEVEL OF URBANIZATION[b] (%)	LEVEL OF ELECTRICITY ACCESS FOR URBAN POPULATION[c] (%)	CO_2 INTENSITY OF ELECTRICITY[d] (tCO_2e/GWh)	NUMBER OF CITIES WITH POPULATION > 1 MILLION	LARGEST CITIES[e] (POPULATION)		
Argentina (40.4M)	92	100	380	3	Buenos Aires (14.2M)	Córdoba (1.5M)	Rosario (1.3M)
Bolivia (10.2M)	67	99	401	3	Santa Cruz (1.7M)	La Paz (1.7M)	Cochabamba (1.0M)
Brazil (195.2M)	87	100	151	21	São Paulo (19.7M)	Rio de Janeiro (12.4M)	Belo Horizonte (5.4M)
Chile (17.2M)	89	100	444	1	Santiago (6.3M)	Valparaíso (0.9M)	Concepción (0.8M)
Colombia (46.4M)	75	100	184	5	Bogotá (8.5M)	Medellín (3.5M)	Cali (2.4M)
Ecuador (15.0M)	67	100	346	2	Guayaquil (2.5M)	Quito (1.6M)	Cuenca (0.3M)
Paraguay (6.5M)	62	100	0	1	Asunción (2.0M)	Ciudad del Este (0.3M)	
Peru (29.3M)	77	99	249	1	Lima (9.0M)	Arequipa (0.8M)	Trujillo (0.7M)
Suriname (0.5M)	69	100	392	0	Paramaribo (0.2M)		
Uruguay (3.4M)	93	100	73	1	Montevideo (1.7M)	Salto (0.1M)	Ciudad de la Costa (0.1M)
Venezuela (29.0M)	93	100	258	5	Caracas (2.9M)	Maracaibo (2.0M)	Valencia (1.6M)

Notes: All tables in Appendix B share these sources:

[a] UN 2014. Values for 2010.

[b] UN-Habitat 2013. Values for 2010.

[c] World Bank 2017. Values for 2014.

[d] IEA 2017. Average for 2013–15.

[e] UN 2014. Values for 2010. Urban agglomerations greater than 300,000 people.

Table B-2 | Central America

COUNTRY (POPULATION)	LEVEL OF URBANIZATION (%)	LEVEL OF ELECTRICITY ACCESS FOR URBAN POPULATION (%)	CO$_2$ INTENSITY OF ELECTRICITY (tCO$_2$e/GWh)	NUMBER OF CITIES WITH POPULATION > 1 MILLION	LARGEST CITIES (POPULATION)		
Costa Rica (4.7M)	64	100	53	1	San José (1.1M)	Heredia (0.4M)	Cartago (0.2M)
Cuba (11.3M)	75	100	774	1	Havana (2.1M)	Santiago de Cuba (0.5M)	Camagüey (0.3M)
Curaçao (0.1M)	N/A[a]	100	688	0	Willemstad (0.1M)		
Dominican Rep. (10.0M)	69	100	564	1	Santo Domingo (2.6M)	Santiago de los Caballeros (0.5M)	Los Alcarrizos (0.3M)
El Salvador (6.2M)	64	98	263	1	San Salvador (1.1M)	Soyapango (0.3M)	Santa Ana (0.2M)
Guatemala (14.3M)	50	94	341	1	Guatemala City (2.6M)	Villa Nueva (0.5M)	Mixco (0.5M)
Haiti (9.9M)	52	53	774	1	Port-au-Prince (2.1M)	Cap-Haïtien (0.2M)	Gonaïves (0.2M)
Honduras (7.6M)	52	99	368	1	Tegucigalpa (1.0M)	San Pedro Sula (0.7M)	Choloma (0.3M)
Jamaica (2.7M)	52	95	641	0	Kingston (0.6M)	Portmore (0.2M)	Spanish Town (0.2M)
Mexico (117.9M)	78	100	470	11	Mexico City (20.1M)	Guadalajara (4.4M)	Monterrey (4.1M)
Nicaragua (5.8M)	57	98	341	0	Managua (0.9M)	León (0.2M)	Masaya (0.1M)
Panama (3.7M)	75	100	330	1	Panama City (1.5M)	David (0.1M)	Colón (0.1M)
Trinidad and Tobago (1.3M)	14	100	618	0	Port of Spain (0.03M)		

Notes:

[a] N/A means a lack of data.

Table B-3 | **Sub-Saharan Africa**

COUNTRY (POPULATION)	LEVEL OF URBANIZATION (%)	LEVEL OF ELECTRICITY ACCESS FOR URBAN POPULATION (%)	CO$_2$ INTENSITY OF ELECTRICITY (tCO$_2$e/GWh)	NUMBER OF CITIES WITH POPULATION > 1 MILLION	LARGEST CITIES (POPULATION)		
Angola (19.5M)	59	51	344	1	Luanda (4.5M)	Huambo (0.9M)	Lubango (0.3M)
Benin (9.5M)	42	58	699	0	Cotonou (0.7M)	Abomey-Calavi (0.5M)	
Botswana (2.0M)	61	71	1806	N/A[a]	Gaborone (N/A)		
Cameroon (20.6M)	58	86	168	2	Douala (2.4M)	Yaoundé (2.3M)	Bamenda (0.3M)
Congo (4.1M)	62	61	264	1	Brazzaville (1.6M)	Pointe-Noire (0.8M)	
Côte d'Ivoire (19.0M)	51	84	446	1	Abidjan (4.2M)	Bouaké (0.7M)	San-Pedro (0.3M)
Dem. Rep. Congo (62.2M)	35	42	1	3	Kinshasa (9.4M)	Lubumbashi (1.6M)	Mbuji-Mayi (1.6M)
Eritrea (5.7M)	22	100	859	0	Asmara (0.7M)		
Ethiopia (87.1M)	17	92	1	1	Addis Ababa (2.9M)	Mekele (0.3M)	Dire Dawa (0.2M)
Gabon (1.6M)	86	97	409	0	Libreville (0.6M)		
Ghana (24.5M)	52	91	268	2	Accra (2.1M)	Kumasi (2.0M)	Sekondi Takoradi (0.5M)
Kenya (40.9M)	22	68	187	1	Nairobi (3.2M)	Mombasa (0.9M)	Nakuru (0.3M)
Mauritius (1.2M)	42	100	812	0	Port Louis (0.1M)		
Mozambique (24.0M)	38	54	39	1	Maputo (1.1M)	Matola (0.8M)	Nampula (0.5M)
Namibia (2.2M)	38	83	30	0	Windhoek (0.3M)		
Niger (15.9M)	17	54	964	0	Niamey (0.9M)	Zinder (0.3M)	
Nigeria (159.7M)	50	78	414	6	Lagos (10.8M)	Kano (3.2M)	Ibadan (2.8M)
Senegal (13.0M)	42	85	616	1	Dakar (2.9M)	Touba (0.8M)	Thiès (0.3M)
South Africa (51.4M)	62	94	978	6	Johannesburg (8.0M)	Cape Town (3.3M)	Durban (2.7M)
Sudan (35.7M)	40	76	220	1	Khartoum (4.5M)	Nyala (0.5M)	Port Sudan (0.4M)
South Sudan (9.9M)	—	8	855	0	Juba (0.3M)		
Togo (6.3M)	43	83	192	0	Lomé (0.8M)		
United. Rep. Tanzania (45.0M)	26	41	436	1	Dar es Salaam (3.9M)	Mwanza (0.6M)	Zanzibar (0.5M)
Zambia (13.2M)	36	62	14	1	Lusaka (1.7M)	Kitwe (0.5M)	Ndola (0.5M)
Zimbabwe (13.1M)	38	83	703	1	Harare (1.5M)	Bulawayo (0.7M)	Chitungwiza (0.3M)

Notes:

[a] N/A means a lack of data.

Table B-4 | **North Africa and Southwest Asia**

COUNTRY (POPULATION)	LEVEL OF URBANIZATION (%)	LEVEL OF ELECTRICITY ACCESS FOR URBAN POPULATION (%)	CO_2 INTENSITY OF ELECTRICITY (tCO_2e/GWh)	NUMBER OF CITIES WITH POPULATION > 1 MILLION	LARGEST CITIES (POPULATION)		
Algeria (37.1M)	67	100	515	1	Algiers (2.4M)	Oran (0.8M)	Constantine (0.4M)
Egypt (78.1M)	43	100	460	2	Cairo (16.9M)	Alexandria (4.3M)	Bur Said (0.6M)
Iraq (31.0M)	66	100	1167	3	Baghdad (5.9M)	Mosul (1.4M)	Erbil (1.0M)
Islamic Rep. Iran (74.5M)	71	100	567	8	Tehran (8.1M)	Mashhad (2.7M)	Esfahan (1.7M)
Jordan (6.5M)	79	100	628	1	Amman (1.1M)	Zarqa (0.4M)	Ar-Rusayfah (0.3M)
Lebanon (4.3M)	87	100	719	1	Beirut (2.0M)		
Libya (6.0M)	78	100	657	1	Tripoli (1.1M)	Benghazi (0.7M)	Misratah (0.5M)
Morocco (31.6M)	58	95	685	3	Casablanca (3.4M)	Rabat (1.8M)	Fes (1.1M)
Syrian Arab Rep. (21.5M)	56	100	578	3	Aleppo (3.1M)	Damascus (2.4M)	Homs (1.3M)
Tunisia (10.6M)	67	100	470	1	Tunis (1.9M)	Safaqis (0.6M)	Susah (0.2M)
Yemen (22.8M)	32	97	740	1	Sana'a (2.3M)	Adan (0.7M)	Taiz (0.6M)

Table B-5 | South, East, and Southeast Asia

COUNTRY (POPULATION)	LEVEL OF URBANIZATION (%)	LEVEL OF ELECTRICITY ACCESS FOR URBAN POPULATION (%)	CO_2 INTENSITY OF ELECTRICITY (tCO_2e/GWh)	NUMBER OF CITIES WITH POPULATION > 1 MILLION	LARGEST CITIES (POPULATION)		
Bangladesh (151.1M)	28	91	579	3	Dhaka (14.7M)	Chittagong (4.1M)	Khulna (1.1M)
Cambodia (14.4M)	20	97	448	1	Phnom Penh (1.5M)	Siem Reap (0.2M)	Battambang (0.1M)
China (1,359.8M)	47	100	684	85	Shanghai (20.0M)	Beijing (16.2M)	Shenzhen (10.2M)
India (1,205.6M)	30	98	787	49	Delhi (21.9M)	Mumbai (19.4M)	Kolkata (14.3M)
Indonesia (240.7M)	44	100	713	7	Jakarta (9.6M)	Surabaya (2.8M)	Bandung (2.4M)
Malaysia (28.3M)	72	100	682	1	Kuala Lumpur (5.8M)	Johor Bahru (0.8M)	Ipoh (0.7M)
Mongolia (2.7M)	62	100	1303	1	Ulaanbaatar (1.1M)		
Myanmar (51.9M)	34	86	266	2	Yangon (4.3M)	Mandalay (1.0M)	Naypyidaw (0.9M)
Nepal (26.8M)	19	98	2	0	Kathmandu (0.9M)	Pokhara (0.3M)	Lalitpur (0.2M)
Pakistan (173.1M)	36	100	414	9	Karachi (14.1M)	Lahore (7.5M)	Faisalabad (3.0M)
Philippines (93.4M)	49	97	598	2	Manila (11.9M)	Davao City (1.5M)	Cebu City (0.9M)
Sri Lanka (20.8M)	14	98	465	0	Colombo (0.7M)	Kaduwela (0.3M)	Maharagama (0.2M)
Thailand (66.4M)	34	100	525	2	Bangkok (8.2M)	Samut Prakan (1.1M)	
Vietnam (89.0M)	30	100	405	2	Ho Chi Minh City (6.2M)	Hanoi (2.8M)	Hai Phong (0.9M)

ENDNOTES

1. Access is defined as the percentage of the population with access to electricity. Access data are collected from industry, national surveys, and international sources (World Bank 2016).

2. Carbon-free electricity can include nuclear power generation, although there are a variety of challenges associated with nuclear energy, which may remove it as an option in some countries.

3. Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Japan, Mexico, Russia, South Africa, South Korea, the United Kingdom, and the United States.

4. The rate at which the carbon intensity of electricity is decreasing is also important. See changes over time at the national level in Appendix A.

5. Authors' calculations based on EIA (2017).

6. Authors' calculations based on EIA (2017).

7. The level of electricity access in urban Argentina is reported at 89 percent, which technically is just below our 90 percent threshold.

8. Authors' analysis based on energy data from Kennedy et al. (2015) and vehicle characteristics assumed by Hawkins et al. (2013).

9. Authors' analysis based on energy data from Kennedy et al. (2015) and vehicle characteristics assumed by Hawkins et al. (2013).

10. However, one aspect of local air pollution from transport may not change to a large degree. A recent review by Timmers and Achten (2016) found that electric vehicles result in PM10 emissions equal to that of internal combustion engines, while PM2.5 levels were only slightly lower, on account of non-exhaust emissions (e.g., tire and brake wear). PM10 stands for particulate matter that is 10 micrometers or less in diameter, and PM2.5 stands for particulate matter that is 2.5 micrometers or less in diameter.

11. Only low- and middle-income countries in 2016, with the exception of Chile, Curacao, Seychelles, Trinidad and Tobago, and Uruguay, according to World Bank (2016).

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ABOUT WRI

World Resources Institute is a global research organization that turns big ideas into action at the nexus of environment, economic opportunity, and human well-being.

Our Challenge

Natural resources are at the foundation of economic opportunity and human well-being. But today, we are depleting Earth's resources at rates that are not sustainable, endangering economies and people's lives. People depend on clean water, fertile land, healthy forests, and a stable climate. Livable cities and clean energy are essential for a sustainable planet. We must address these urgent, global challenges this decade.

Our Vision

We envision an equitable and prosperous planet driven by the wise management of natural resources. We aspire to create a world where the actions of government, business, and communities combine to eliminate poverty and sustain the natural environment for all people.

Our Approach

COUNT IT

We start with data. We conduct independent research and draw on the latest technology to develop new insights and recommendations. Our rigorous analysis identifies risks, unveils opportunities, and informs smart strategies. We focus our efforts on influential and emerging economies where the future of sustainability will be determined.

CHANGE IT

We use our research to influence government policies, business strategies, and civil society action. We test projects with communities, companies, and government agencies to build a strong evidence base. Then, we work with partners to deliver change on the ground that alleviates poverty and strengthens society. We hold ourselves accountable to ensure our outcomes will be bold and enduring.

SCALE IT

We don't think small. Once tested, we work with partners to adopt and expand our efforts regionally and globally. We engage with decision-makers to carry out our ideas and elevate our impact. We measure success through government and business actions that improve people's lives and sustain a healthy environment.