

# Electricity Access Threshold for Meeting Non-Energy SDG Targets

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## Abstract

Access to sufficient amounts of energy is a prerequisite for development of human well-being. Analysis presented in this paper shows that multiple sustainable development targets are linked to per capita access to electricity in particular and demonstrate a threshold behavior below which sustainable development targets have not been met historically. The present work relates to the broad literature on the Sustainable Development Goals (SDGs), recognizing the interconnectedness of energy access (SDG7) and other development goals. Although targets are provided for each of the 17 goals, not all targets are quantified, leaving room for ambiguity in fulfilling, for example, the goal of “ensuring access to affordable, reliable, sustainable and modern energy for all.” The focus of this work is an extension of our previous finding that a per capita societal electricity consumption threshold of about 400kWh is strongly related to meeting outcomes for health indicators related specifically to SDG targets. In this contribution we further examine this quantitative relationship between electricity access as correlated with education, sanitation, food security and health outcomes, posing the question in the form, “Below what minimum societal per capita access to electricity is a country very unlikely to meet SDG targets?”

## 1. Introduction

Energy access plays a key role in economic and human development, as exemplified in Sustainable Development Goal (SDG) 7: “ensure access to affordable, reliable, sustainable and modern energy for all.” At the same time, it is recognized that access to energy is not an end in itself, but rather that there are important links between access to sustainable modern energy and the achievement of other SDGs. There is a large literature on both requisite levels of energy access (Krugman and Goldemberg 1983; Goldemberg et al. 1985; Sathaye et al. 2011; S Pachauri et al. 2012; Nussbaumer, Bazilian, and Modi 2012; Bhatia and Angelou 2015; Rao and Pachauri 2017; Pelz, Pachauri, and Groh 2018; Jain and Shahidi 2019), especially at the household level (Shonali Pachauri and Spreng 2002; S. Pachauri et al. 2004; Shonali Pachauri et al. 2013; Groh, Pachauri, and Rao 2016), as well as a growing literature on SDG synergies (and less commonly, mutual barriers) (Collste, Pedercini, and Cornell 2017; Weitz et al. 2017; Taylor et al. 2017; McCollum et al. 2018).

In this paper we go beyond the qualitative linkages between energy access and other SDGs and look at development indicator data for most countries, examining how specific levels of average per capita annual energy (or electricity) consumption is correlated with achieving specific SDG quantitative targets.

## 2. Energy Access and Human Development

The Human Development Index (HDI) is one measure of average quality of

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life for a country (UNDP 2016). Expressed on a scale between 0 and 1, the HDI is a composite index of economic wealth, education, and health indicators. Human Development Index data from the United Nations Development Programme form part of the Human Development Report published each year. Data for both the overall index as well as for the individual components are publicly available (at <http://hdr.undp.org/en/content/human-development-index-hdi>). For the present work, chosen years for the HDI are matched to the years for which energy data are available, usually 2014. A plot of HDI values vs. final energy consumption per person (IEA 2016) as shown in Fig. 1 results in a characteristic trend toward higher levels of HDI with greater energy consumption, at least for lower levels of HDI. Beyond a certain level (greater than an HDI of about 0.8 and final energy consumption of 50GJ per capita annually), however, increased energy consumption does not correlate with an increase in well-being. The diamonds in Fig. 1 represent a snapshot of HDI values in the year 2014 for 142 countries for which both HDI and final energy data were available. The United Nations Development Programme considered ranges of human development (2014): <0.55, low (12% of world population); 0.55-0.70, medium (37%); 0.70-0.80, high (31%); >0.80, very high (20%).

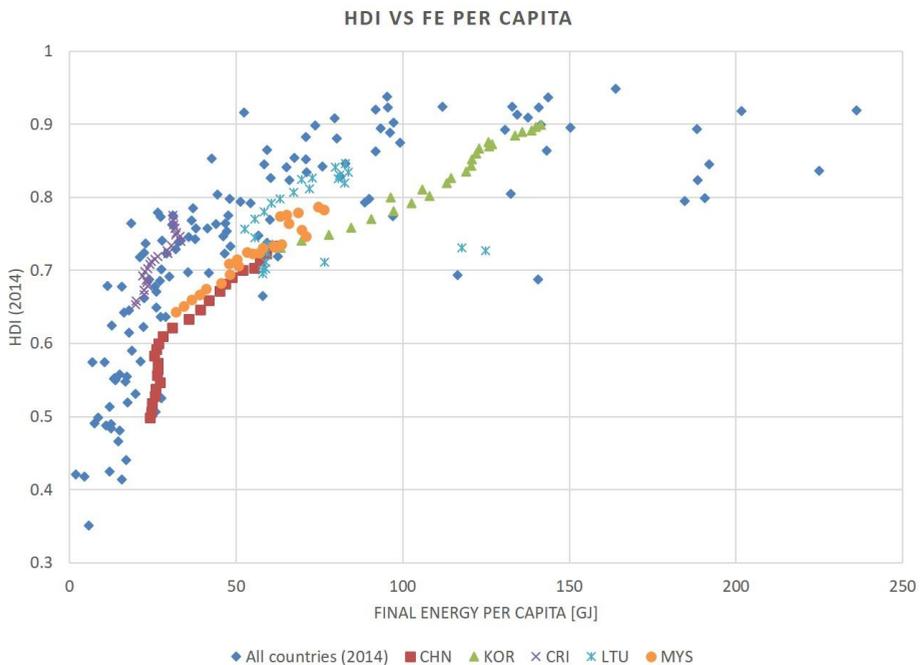


Figure 1 - Human Development Index as a function of per capita final (i.e. useful) energy. The diamonds are a snapshot of all countries with available data in the year 2014. The other series are for selected individual countries in one-year steps from 1990 to 2014. Individual countries are China, Korea, Costa Rica, Lithuania and Malaysia. Sources of data: UN Development Programme, <http://hdr.undp.org/en/content/human-development-index-hdi> and International Energy Agency, [http://wds.iea.org/wds/ReportFolders/ReportFolders.aspx?CS\\_referer=&CS\\_ChosenLang=en](http://wds.iea.org/wds/ReportFolders/ReportFolders.aspx?CS_referer=&CS_ChosenLang=en) and World Bank, World Data Indicators, <http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators#>

The low-energy, low-HDI end of the scale is most crucial, and leads to the framing we use in what follows. No country at a “very high” level of HDI (above 0.8) has an average availability of final energy of less than 40 GJ per person per year<sup>1</sup>. (In the US, final energy consumption is approximately 200GJ.) Furthermore, we can look at these data to see how several individual countries develop over time (represented by the time series of symbols from 1990-2014), and find that they follow a path that moves through stages represented by the snapshot of countries today, tracking from the lower left toward the upper right of the plot.

### 3. HDI and Electricity Consumption

We further narrow our focus to electricity, as the most modern and flexible of energy sources, and examine individual components of the HDI (GDP, life expectancy, years of schooling). The relationship between the Human Development Index (HDI) and per capita electricity consumption is shown in Fig. 2. Data for 172 countries are shown in Fig. 2a, representing about 97% of the world’s population for which data on both HDI (vertical axis) and per capita electricity consumption (kWh per person per year, horizontal axis) are available for the year 2014<sup>2</sup>. From Fig. 2b, it appears that achieving an HDI of greater than 0.7 is inconsistent with having per capita electrification of less than 1000 kWh annually. This set of countries represents about 42% of the world’s country population. Looking even further (Fig. 2c), countries with greater than 400 kWh per capita are likely to have an HDI >0.55, and those with access less than ~400kWh/capita all have an HDI of <0.6 (Fig. 2d). It is these countries that are the focus of this paper. We choose the value of 400 kWh as a marker based not only on this observation of data, but also on previous work we have done looking at achievement of SDG numerical targets for health indicators (Brecha 2019). Approximately 15% of the world’s population lives in countries with access to less than an average of 400 kWh per capita, representing at least one billion people.

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<sup>1</sup> In energy units, 40 GJ is approximately 11,000 kWh, or one “tonne of oil equivalent (toe)”. An average power of 1kW is equivalent to an annual energy consumption 8760 kWh. To the level of precision needed here, we can consider 40GJ per capita and 1 toe and 1kW to all be equivalent expressions for the same level of energy access.

<sup>2</sup> Wealthy countries, as represented by the Organization for Economic Cooperation and Development (OECD) have per capita annual electricity consumption of >5000 kWh, with an average of over 8000 kWh/person/year, with the United States at more than 12,000kWh/person/year (average value including all sectors of the economy)

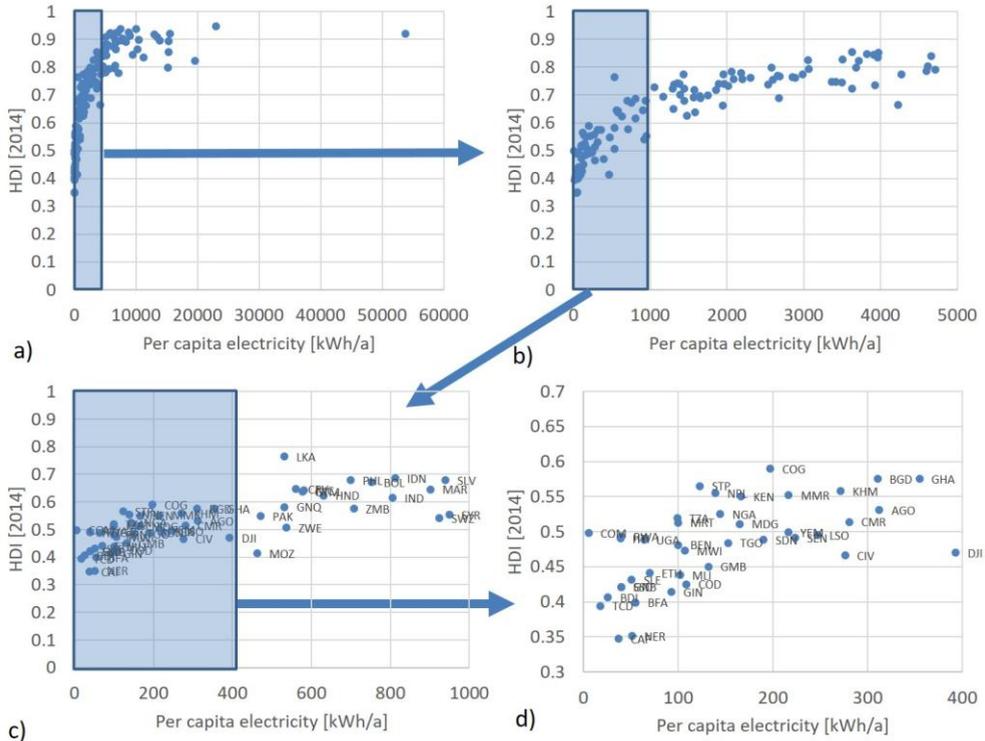


Figure 2 - Human Development Index as a function of per capita electricity consumption in kWh per year [kWh/a]. Each point represents one country with data from 2014. Source: World Development Indicators, <http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators#> and <http://hdr.undp.org/en/content/human-development-index-hdi>

#### 4. Education, Health, Wealth, and Life Expectancy

One component of the HDI is mean years of schooling. Access to education is also addressed by SDG 4, to “ensure inclusive and quality education for all and promote lifelong learning” (UN General Assembly 2015), with targets involving universal access, literacy and numeracy, and appropriate facilities. Fig. 3a shows histograms for mean years of schooling (UNDP 2016), with different country groups divided by per capita electricity consumption (World Bank 2017). No country with electricity access lower than 400 kWh per capita has more than primary school education levels on average. In contrast, countries with greater than 400kWh of per capita average annual electricity consumption are very unlikely to average less than nearly eight years of schooling (Education Index of 0.6-0.7). Given that one specific target for SDG 4 is “By 2030, ensure that all girls and boys complete free, equitable and quality primary and secondary education,” it appears that only countries with more than at least 400 kWh of per capita annual electricity consumption meet that target.

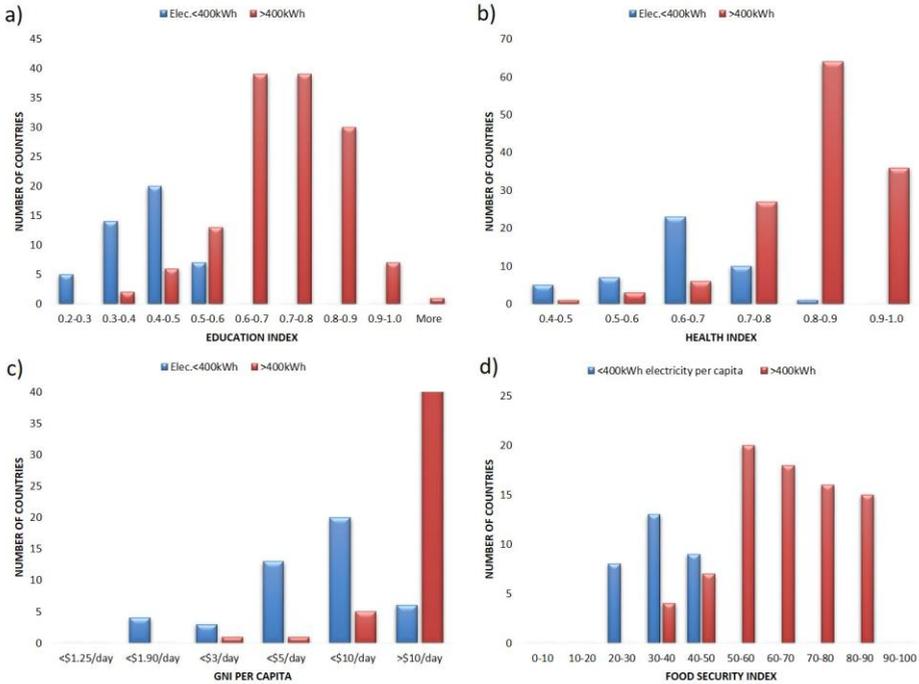


Figure 3 – a) Education index (mean and expected years of schooling) for different electricity consumption ranges. b) Histogram of the number of countries with different ranges of life expectancy at birth. c) Per capita Gross National Income (GNI) for different electricity consumption groups. d) Global Food Security index for 111 countries. Countries are grouped by how much electricity is consumed on average per capita per year. Groups of countries are those with <400kWh per capita average annual consumption (blue bars), and those with >400kWh (red bars). Data from UNDP, <http://hdr.undp.org/en/data>, for food security, from <http://foodsecurityindex.eiu.com/>.

In Fig. 3b the world is again divided into countries that have, on average, access to either less than or more than 400kWh/person/year. If a country has access to less than 400kWh of electricity per person, it is highly likely that the average life expectancy at birth is greater than 70 years. Average life expectancy at birth is between 70-85 years for those with higher electricity access. In addition to being a component of HDI, life expectancy links energy access to SDG3, “Ensure healthy lives and promote well-being for all at all ages.” Our previous work has made this linkage more explicit and forms the basis for the threshold electricity consumption level used here. (Brecha 2019)

Fig. 3c is a histogram of the different electricity-consumption groups, each divided into bins corresponding to different per capita incomes. Of countries with per capita GNI corresponding to less than \$5/day (more than twice the poverty definition of \$1.90/day), 90% have average per capita electricity consumption under 400kWh/year. Conversely, of those countries with per capita GNI greater than \$10/day, only 5% have <400kWh/year electricity consumption. The GNI measure also corresponds to an augmented version of SDG1, to “end poverty in all its forms, everywhere” (UN General Assembly 2015). For comparison, Italy has a GNI per capita of ~\$100/day, the United States about 50%

more than that.

As another example, SDG 2 calls for the world to “End hunger, achieve food security and improved nutrition and promote sustainable agriculture,” with targets to “By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round” and “By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons.” One way to expressing these targets is in terms of the Global Food Security Index<sup>3</sup> an aggregate index on a scale of 0-100, with components of availability, affordability and quality, the familiar pattern from other development indicators appears. We see in Fig. 3d that no country with less than 400kWh per capita electricity consumption achieves a food security index value of >50, whereas those countries with higher per capita electricity consumption are very unlikely to have a low food security index (under 50).

### **5. Energy Requirements for All Those with Less than 400 kWh per Capita Average Societal Access**

The population in 2015 for those countries with less than 400kWh per capita electricity consumption is 920 million. The UN projects in its “medium variant” scenario an increase in population to 1.6 billion in 2030 for these same countries (UN Dept of Economic and Social Affairs 2017). Countries currently with less than 400 kWh per capita electricity consumption have an average of about 170kWh per capita, so total electricity consumption for the 920 million people in these countries is 160 billion kWh (160 TWh or Terrawatt-hours) as shown in Fig. 4 where curve a) is a plot of cumulative electricity consumption as a function of cumulative total population ends at the point (920[million], 160[TWh]). Taking as a target that each of these countries should have an average per capita electricity consumption of 400kWh by 2030 leads to curve b) in Fig. 4, which shows for this simplified example a total consumption of 640 TWh, representing a compounded annual growth rate of 9.3%/year. Curve c) in Fig. 4 is simply the 9.3% yearly exponential increase in per capita electricity consumption from its current level to the target level in the year 2030, with population instead of time as the abscissa.

The International Energy Agency (IEA) in its 2017 World Energy Outlook Special Report on Energy Access (IEA 2017) focuses mainly on household electricity (and cooking energy) access, while acknowledging the importance of access to modern sources of energy for productive needs such as the services discussed above. The “Energy for All” scenario looks at providing access at the initial level of 250 kWh per rural household (and 500 kWh for urban households) with a gradual increase thereafter, such that universal access is achieved by 2030. Compared to the baseline “New Policies Scenario” the more ambitious scenario results in additional demand of 119 TWh of electricity demand by 2030, at an additional cumulative investment cost of \$391 billion, or an average of \$28 billion per year. The latter represents 1.7% of annual global energy

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<sup>3</sup> <http://foodsecurityindex.eiu.com/>

system investments. (IEA 2017)

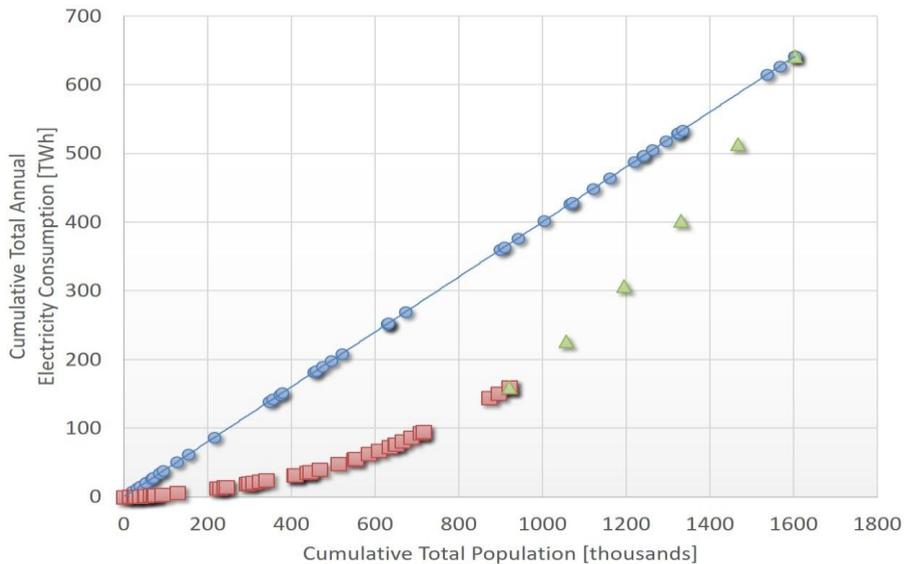


Figure 4 - Cumulative electricity consumption as a function of cumulative population for all countries with <math><400\text{kWh}</math> per capita average annual consumption.

Furthermore, the additional access to electricity for 674 million people by 2030 compared to the New Policy Scenario implies approximately 175 kWh per capita per year access. For the example we have given above, and current consumption levels across the energy-poor countries, approximately two times as much would be needed to satisfy the goal of reaching 400 kWh per capita electricity availability. The IEA estimates from their modeling that additional investments of \$391 billion are necessary for their goal; a rough extrapolation would double this to \$800 billion in cumulative investments by 2030, or ~\$60 billion per year, representing approximately 3.5% of global investment in energy systems. (IEA 2017)

## 6. Discussion

Countries with average per capita electricity consumption of less than 400kWh per year have uniformly poor human development indicators, and few if any at this level of consumption meet SDG targets for health, wealth, education, sanitation or food security. On the other hand, this can be expressed by stating, from the same data, that there are relatively few countries with average electricity access of >400kWh per capita that have an average number of years of education less than eight, or life expectancy at birth of less than 70 years, or high mortality rates for women, infants or young children. For reference, 400 kWh per capita is approximately one-fifth the level of electricity use in the US in 1950; the SDG indicators for life expectancy and average educational attainment are roughly those for the US at that time as well. If it is possible to achieve

society-wide targets at lower levels of electricity consumption, then it must be shown how that is to be accomplished. For example, efficient appliances and lighting may contribute to lowering the bar for energy-related indicators. It is also clear that energy access must be planned and implemented in a systemic fashion so that household and productive uses are addressed effectively; in that sense, it is also important to consider SDGs that support the goals and targets discussed here: SDG 9 - Industry, Innovation and Infrastructure; SDG 16 - Peace, Justice and Strong Institutions; and SDG 17 - Partnership for the Goals.

One possible objection to this analysis is that electricity access has been chosen as the independent variable, but that other variables could have been chosen. In other words, energy access might be just a proxy for “wealth” or GNI/capita. In fact, the two are closely related. Interestingly, the threshold behavior identified in our previous work (Brecha 2019), from which we derive the per capita consumption level of approximately 400kWh used in the present analysis, is not as evident as a function of GDP as it is in terms of electricity access. Additionally, it is possible to construct causal chains showing that it truly is energy access that is a key to achieving these (and possibly other) SDGs, and not just increase in wealth. Although there is the potential for conflicts between SDGs (Stechow et al. 2016; McCollum et al. 2018; Nilsson, Griggs, and Visbeck 2016; Weitz et al. 2017) clear connections have been made by others between access to electricity in support of achieving other goals (McCollum et al. 2018).

In Table 1 we compile linkages between the SDGs considered in this paper and access to electricity (and more broadly, other modern energy sources). The examples here are mainly based on McCollum et al. In that work, there are also potential negative aspects of energy access, depending on the particular sources used; here we are concerned mainly with the implications for having access to enough electricity (and at the relatively low levels correlated with achieving SDG targets).

**Table 1** - Summary of key synergies between access to electricity and other SDGs, focusing on the causal connections

<b>SDG 1 - Poverty</b>	<b>SDG 2 - Hunger</b>	<b>SDG 3 - Health</b>	<b>SDG 4 - Education</b>	<b>SDG 6 – Water and Sanitation</b>
Modern energy (electricity) fundamental for development	Energy access can help reduce post-harvest losses	Electricity allows storage of medicine and vaccines	Lighting allows more opportunity for studying at home	Electricity can allow access to pumping for safer drinking water
Access to electricity (and other modern energy) frees up time and other resources	Food preservation improved by access to electricity	Improved lighting and equipment power in clinics	Electricity in schools provides better lighting and information technology access	Electricity access will allow for desalination to enhance scarce water resources
		Better food preservation contributes to better health outcomes		Power needed for water treatment

In conclusion, access to modern energy systems, and primarily to electricity, is strongly linked to being able to achieve targets set for many Sustainable Development Goals. Although gains in efficiency in the future as well as some geographical and country-specific factors may affect the exact level of consumption, we have shown here that below a societal level of 400 kWh per capita annually, very few countries have been able to meet SDG targets. Furthermore, even this relatively meager amount of electricity is higher than what is projected for 2030 in international modeling efforts. Therefore, either higher levels of electricity access must be assumed for models to be consistent with the SDGs, or else it is necessary to demonstrate how the SDGs can be achieved without that level of access to modern energy.

## 7. Appendix: Data Sources

Human Development Index data are from the United Nations Development Programme as part of the Human Development Report published each year. Data for both the overall index as well as for the individual components are available at <http://hdr.undp.org/en/content/human-development-index-hdi>. For the present work, chosen years for the HDI are matched to the years for which energy data are available, usually 2014.

Specific data sets used are:

Human Development Index (HDI)	<a href="http://hdr.undp.org/en/indicators/137506">http://hdr.undp.org/en/indicators/137506</a>	S1, S2
Life expectancy at birth	<a href="http://hdr.undp.org/en/indicators/69206">http://hdr.undp.org/en/indicators/69206</a>	S4
Mean years of schooling	<a href="http://hdr.undp.org/en/indicators/103006">http://hdr.undp.org/en/indicators/103006</a>	1
Gross national income (GNI) per capita	<a href="http://hdr.undp.org/en/indicators/141706">http://hdr.undp.org/en/indicators/141706</a>	
Final energy use [GJ]	IEA Energy Balances	S1

Data for other indicators are taken from the World Bank database of World Development Indicators (WDI) that can be found at <https://data.worldbank.org/indicator>. Specific indicators used here are:

Indicator name	Indicator code	Fig.
Electric power consumption (kWh per capita)	EG.USE.ELEC.KH.PC	S2
Energy use (kg of oil equivalent per capita)	EG.USE.PCAP.KG.OE	
GDP per capita, PPP (constant 2011 international \$)	NY.GDP.PCAP.PP.KD	S3
Maternal mortality ratio (modeled estimate, per 100,000 live births)	SH.STA.MMRT	2a
Mortality rate, under-5 (per 1,000 live births)	SH.DYN.MORT	2c
Mortality rate, neonatal (per 1,000 live births)	SH.DYN.NMRT	2b
Life expectancy at birth, total (years)	SP.DYN.LE00.IN	
Access to clean fuels and technologies for cooking (% of population)	EG.CFT.ACCS.ZS	
Improved sanitation facilities (% of population with access)	SH.STA.ACSN	2d
Population, total	SP.POP.TOTL	

Population data, both current and projected increases, are taken from the United Nations World Population Prospects 2015 update, POP/DB/WPP/Rev.2015/POP/F01-1.

For many African countries, the WDI database does not include per capita electricity consumption. To fill in these gaps, the United Nations Environment Programme *Atlas of Africa Energy Resources* was used (UNEP 2017) as were data from the United States Energy Information Administration (<https://www.eia.gov/>).

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