The Energy ACCESS Dividend in Honduras and Haiti

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THE ENERGY ACCESS DIVIDEND IN HONDURAS AND HAITI

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Executive Summary

Access to modern energy services is an enabler of opportunity and a pillar that supports job creation, economic growth, and improved social well-being. While the Sustainable Development Goals (SDGs) identify universal access to safe, reliable, sustainable, and modern energy as one of the seventeen goals to promote sustainable global development, it is clear that universal energy access also affects the achievement of many of the other SDGs, including the eradication of poverty, education, health, economic growth, reduced inequalities, and climate action (Barron and Torero, 2017; Lee et al., 2016; SEforALL and Power for All, 2017). Nearly 1.1 billion people globally still lack access to basic electricity and projections indicate that 674 million people will remain unelectrified in 2030, suggesting that a "business-as-usual" approach to electrification will not be sufficient to reach the SDG target (IEA, 2017). Beyond basic access, far more people lack the higher levels of electricity access needed to support income generation through small businesses, agriculture, industry, health services, and other productive uses.

Global patterns in electricity access show uneven progress towards universal electrification. Nearly 90 percent of households lacking basic electricity access are rural (IEA, 2017). Although reaching rural households through grid connections continues to present challenges to expanding access, alternative electricity solutions including solar home systems and micro-grids are allowing for more rapid expansion of access in rural and peri-urban areas. These off-grid platforms have been successful in concentrated areas, suggesting the potential to scale quickly in new markets.

Indeed, there have never been more possible pathways to universal electrification than there are today. Governments face important decisions regarding how to balance power quality, quantity, and reliability priorities with how to ensure all populations receive access as quickly as possible. Identifying the pathway that best fits the needs of the country requires a detailed understanding of the benefits that accrue to different populations under different scenarios and timelines.

This report attempts to quantify and monetize these and other benefits generated through accelerated electricity access. Electricity access saves households money on lighting and cell phone charging costs. It facilitates ownership of radios, fans, televisions, and refrigerators. It allows for increased study time in the evening and reduced emissions of harmful pollutants. The report builds on an existing framework for measuring the dividends of electrification, which was developed to estimate the potential benefits of increasing the pace of electrification through a series of three case studies examining energy access in Kenya, Ethiopia, and Bangladesh (SEforALL and Power for All, 2017). It builds on this methodology and applies it for the first time in Latin America, a region that is doing comparatively well in electrifying households, with 97 percent of the population currently having some level of electricity access, but where 17 million people still lack access and where reliability remains a major challenge.

The concept of the Energy Access Dividend (EAD) is to quantify the electrification benefits forgone over a country's business-as-usual electrification transition. It is calculated based on the estimated benefits of electrification forgone over this transition and the time horizon over which households remain without electricity access.

This report presents results of the EAD model for Haiti and Honduras, two countries that represent different electricity access situations in Latin America. In both settings, energy poverty continues to pose important challenges, but the nature of the problem is quite different. Haiti has the lowest rates of electricity access in the Western Hemisphere, while Honduras has much higher connection rates but still faces problems related to last mile connections and electricity quality. The contrasting nature of the challenge in these two settings provide a useful comparison that also helps to better demonstrate the value of EAD in policymaking. Furthermore, as data availability differs substantially between the two countries, this report illustrates how detailed household-level survey data can be a powerful addition to national-level statistics by demonstrating how benefits accrue in different ways to different populations within a country. Designed as a tool for policy planning, the dividends presented in this report for Haiti and Honduras are intended to highlight the role of electrification in economic development and offer policymakers a framework for including electrification trade-offs—in terms of technology, pace, and level—in policy planning and design.

Impacts of energy access

Electricity access can provide a number of benefits to households, which is why it is a critical component of overall economic development and poverty alleviation. The initial EAD framework identifies thirteen categories of potential benefits, which capture a useful picture of the many ways households benefit from access. These include: financial benefits including savings on lighting, use of savings, savings on phone charging; environmental benefits including health benefits and emissions reductions; time use changes including study time, time spent in income-generating work, time spent in domestic work, time required for communication, and leisure; and asset access including cell phones, radios and televisions, and refrigerators (SEforALL and Power for All, 2017). In addition to these household benefits, there is also potential for productive benefits of electricity through the use of electricity in small industry or in agricultural production, as well as community benefits such as increased property and home values and nighttime safety and security.

These categories of benefits suggest that electricity access exists along a continuum rather than as a binary distinction. Households enjoying basic electricity access may experience benefits associated with reduced lighting and cell phone charging expenditures and lowered emissions; however, their level of electricity access may not be sufficient to power many electricity-utilizing assets like televisions and refrigerators and not reliant enough to power small businesses, irrigation equipment, or other productive applications. To acknowledge and quantify these differing levels within the electricity access continuum, this report utilizes the Multi-Tier Framework (MTF), developed by the World Bank, which categorizes households into energy access tiers depending on the quality, capacity, daytime and evening duration, reliability, legality, and safety of their access (Bhatia and Angelou, 2015). The MTF tiers range from 1—indicating a low level of basic access that is available for about four hours per day and is sufficient to power electric lights and charge small electronics—to tier 5—indicating grid-quality electricity available for at least 23 hours per day. Unelectrified households are categorized as tier 0.

Previous research provides the starting point for determining and quantifying these benefits. Gaps in the research demonstrate areas in which data limitations may preclude the valuation of certain benefits within the EAD framework. This extended EAD framework incorporates benefits associated with savings on lighting and cell phone charging expenditures, reduced emissions, changes in study time, asset ownership of four key household assets (radio, fan, television, and refrigerator), and improved household productivity related to electricity reliability. Gaps in the existing research and lack of data prevent the inclusion of additional benefit categories associated with energy access like how households use their financial savings, improved health, time use changes outside of increased study time, increased commercial and industrial productivity, and broader community effects.

Calculating the Energy Access Dividend

This report expands the original EAD framework in three key ways: (i) it values a wider set of electrification benefits; (ii) it converts all benefits into monetary values to present one, comprehensive EAD estimate; and (iii) it incorporates levels, or tiers, of electricity access, estimated using household-level survey data, directly into the EAD calculation for each benefit.

The basic EAD focuses on the benefits of initial, basic access to electricity and is presented for both Haiti and Honduras. This framework is useful for considering the analysis possible with limited country-level data, demonstrating that even with basic country-level statistics, the EAD framework provides valuable insights for energy policy development and design. The benefits of electrification as they relate to reduced kerosene expenditures for lighting, reduced expenditures on cell phone charging, reduced emissions, and changes in study time make up the benefits portion of this basic EAD. These benefits are attributed to each household without electricity along the electrification transition time horizon to generate an aggregated dividend calculation for the country as a whole.

The extended EAD expands on this basic framework by incorporating both the benefits of initial access as well as benefits of asset ownership and improved household productivity that accrue as households climb to higher energy access tiers. This extended framework allows for the comparison of benefits across different electrification scenarios. Given the availability of household-level survey data for Honduras (World Bank and ESMAP, 2018) and the lack of such detailed data for Haiti, the extended EAD is presented only for Honduras.*

The Energy Access Dividend for Haiti

In 2016, Haiti's rate of electrification was just 39 percent, leaving a population of over 6.6 million people without electricity access (IEA and World Bank, 2017). Electrification rates are not constant across the country; 65 percent of the population in urban areas has access to electricity, while electricity access is available only to approximately 2 percent of the rural population (IEA and World Bank, 2017). Haiti accounts for 43 percent of those without access in all of Latin America. Based on existing rates of electrification growth, Haiti is not projected to achieve universal electrification until 2150. Given these low rates of electricity access, the EAD associated with universal basic access in Haiti provides an estimate of the level of well-being improvements that are likely to be left on the table absent a radical departure from its current electrification path.

In Haiti, the average unelectrified household would gain an annual benefit of 1153 Haitian gourdes ($16.20 USD) from reduced kerosene consumption for lighting, 704 Haitian gourdes ($10 USD) from reduced cell phone charging expenditures, and 228 Haitian gourdes ($3.80 USD) from reduced climate-affecting emissions (monetized using the social cost of carbon) if the transition to universal basic electrification happened immediately, rather than over the business-as-usual electrification trajectory. This yields a total annual EAD of nearly $30 USD per unelectrified household in Haiti.

The aggregate EAD for Haiti over the period of 2016-2050, which incorporates the forgone benefits of electrification as they relate to lighting expenditures, emissions, and cell phone charging, amounts to 30 billion Haitian gourdes, or $423 million USD (the total undiscounted benefits are 128.8 billion gourdes, and the present value using a discount rate of 5 percent is 55.5 billion gourdes). Over half of these benefits result from transitioning away from kerosene and towards electricity for lighting. A third of the benefits are associated with cell phone charging inside the home, and the remainder of the EAD benefits are associated with reductions in climate pollution from kerosene combustion.

* Disclaimer: The Honduras Multi-Tier Framework data is not yet officially published or endorsed by the Government of Honduras and therefore is being used for demonstrative purposes only.

The Energy Access Dividend for Honduras

In 2016, Honduras's rate of electrification was 82 percent, leaving 1 million people without access to electricity (World Bank and ESMAP, 2018)[2]. Projecting current rates of electrification forward, urban Honduras would reach universal electrification by 2028—achieving the access target of SDG 7—while rural Honduras would reach universal electrification by 2038, falling short of the SDG7 access target. Additionally, Table 1 shows that just 38 percent of Hondurans have reliable, high-quality electricity access, indicating that significant additional benefits could be achieved by moving households up the tiers of access. So, the electricity access challenge facing Honduras is in reaching last-mile households in remote, rural communities as well as improving the quality and reliability of access for those already connected.

This report presents four energy access scenarios for Honduras, calculating the EAD for each electrification pathway. Given the availability of household-level survey data, which allows for the classification of Honduran households into energy access tiers (World Bank and ESMAP, 2018), each of these scenarios is based on tiered access according to the MTF definitions. Table 1 shows the distribution of households across tiers for Honduras.

Table 1: Percent of population across energy tiers, Honduras

Tier	Urban	Rural	Combined
Tier 0	2.34	30.37	18.01
Tier 1	0.64	5.21	3.20
Tier 2	2.82	4.38	3.69
Tier 3	37.71	21.28	28.53
Tier 4	11.60	6.54	8.77
Tier 5	44.88	32.21	37.80

First, under the universal access to basic electricity scenario (tier 1), the aggregated present value of the EAD (using a 12 percent discount rate) amounts to 1.3 billion lempira, or $54 million USD (the total undiscounted benefits are 2.7 billion lempira, and the present value using a discount rate of 5 percent is 1.8 billion lempira). These benefits come through reduced expenditures on kerosene and cell phone charging outside the home as well as benefits from reduced climate-affecting emissions, monetized using the social cost of carbon. Benefits are accrued to unelectrified households across the electrification trajectory and discounted to generate an aggregate present value of the EAD.

2. In some instances, the values from the multi-tier framework survey data from Honduras (World Bank and ESMAP, 2018) are inconsistent with nationally reported statistics. In these cases, we defer to the multi-tier framework data as these data provide the basis for our empirical analysis.

The extended EAD is then calculated for three more scenarios: universal tier 5 electrification, universal tier 3 electrification, and a hybrid scenario of universal tier 5 electrification in urban areas and universal tier 3 electrification in rural areas. These scenarios align with electrification policies associated with extended grid access (universal tier 5), off-grid solutions such as microgrids and solar home systems (universal tier 3), and a mix of grid and off-grid solutions (hybrid scenario). In addition to the benefits associated with basic electricity access, the extended EAD incorporates benefits associated with higher tier access including increased study time, asset ownership, and electricity reliability.

The present value (12 percent discount rate) of the extended EAD for universal tier 5 electrification in Honduras is 6.4 billion lempiras or $267 million USD (using a 5 percent discount rate, this estimate rises to 10.3 billion lempiras, and the undiscounted total is 16.9 billion lempiras). For universal tier 3 electrification, the present value of the extended EAD is 3.2 billion lempiras ($132 million USD). Finally, the present value of the extended EAD for universal tier 5 electrification in urban areas and universal tier 3 electrification in rural areas is 6.1 billion lempiras or $255 million USD (using a 5 percent discount rate, this estimate rises to 9.9 billion lempiras, and the undiscounted total is 16.1 billion lempiras).

Comparison across EAD scenarios demonstrates that the benefits of electricity access extend far beyond a household's access to basic, tier 1 electricity. A binary treatment of electricity that considers only basic access fails to capture substantial benefits in Honduras, an intuitive but important finding that is consistent with past energy access research. Clearly, access to four hours of electricity a day with the capacity to power light bulbs and charge phones presents vastly different potential benefits than access to twenty-four hours of electricity a day with the capacity to power large appliances and machines. These extended EAD calculations provide an initial framework for considering and valuing the differences associated with the quality of energy access. Even countries like Honduras that have made impressive strides towards universal electrification may be missing significant benefits if additional resources are not allocated to improving the quality and reliability of modern energy access.

Conclusions

Electrification decisions are among the most complicated and far-reaching that governments must make, and the ramifications of those decisions have great bearing on how a country is able to support improvements to its citizens' well-being and achieve broader development goals. While governments generally have the tools and methods at their disposal to understand the cost of different electrification options and pathways, there is a lack of rigorous methodologies available for understanding how much those different options provide in terms of benefits for different populations over different timeframes. The EAD can help to fill this critical gap.

The EAD estimates for Haiti and Honduras—and for other countries in the future using this methodology—are intended to elevate the electrification policy dialogue. The approach can be used not only to understand the aggregate level of benefits that electrification can unlock, but it can shed light on which pathways and platforms it can be achieved through, which populations benefit, and how the pace of these investments influences the level of benefits achieved. The pain of potentially expensive electrification investments can be tempered with the positive reality of what those investments could reasonably achieve, which can be invaluable in mobilizing the political will and resources needed to shift to an accelerated energy access pathway.

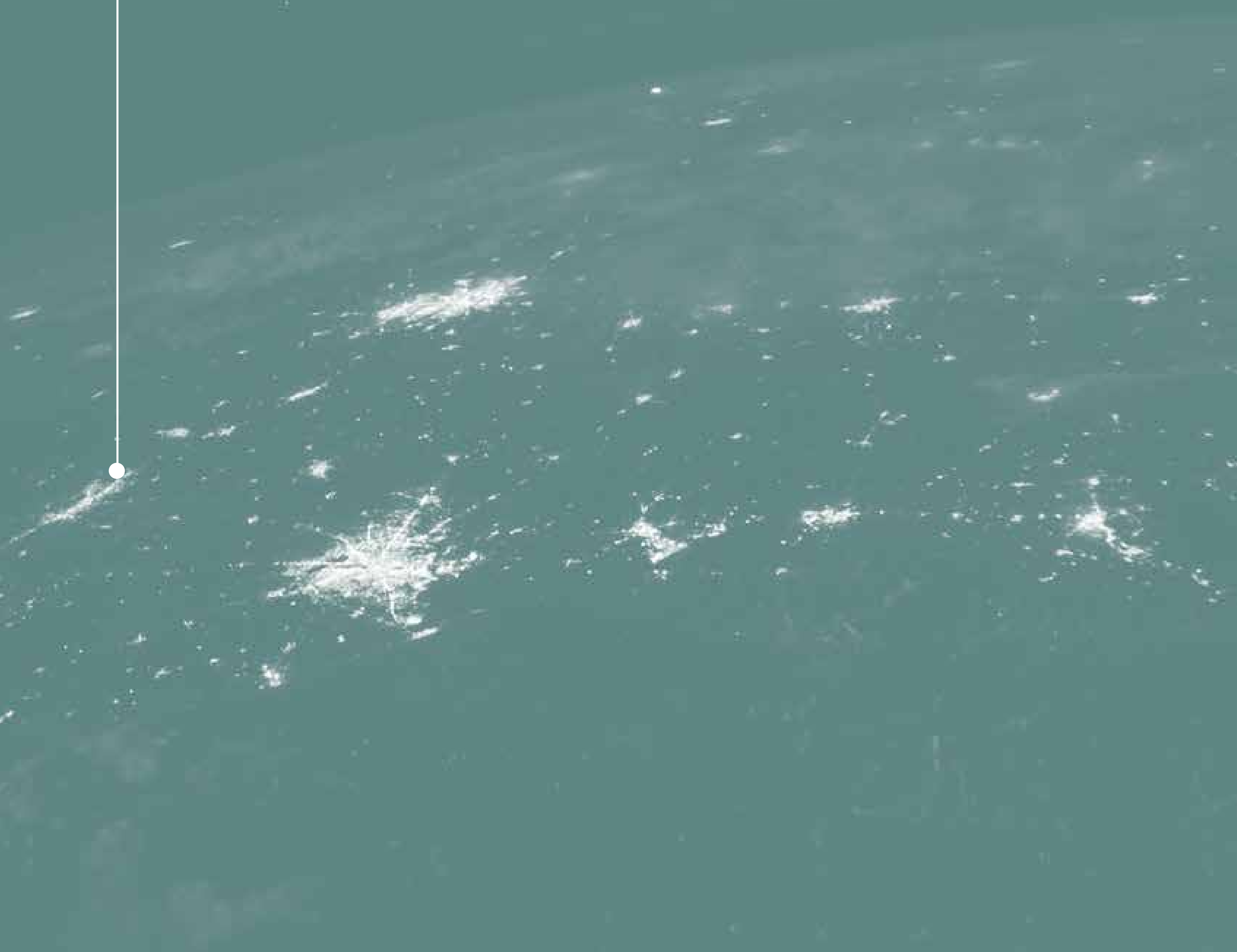
The EAD framework provides a structured approach to weigh the relative benefits of providing accelerated access to rural communities using distributed renewables, compared to service delivered through the grid over a longer timeframe. Similarly, the EAD can provide guidance on the relative gains of extending basic access to more people versus enhancing the access of those already served. It can and should be used in combination with energy demand forecasts, electrification scenario planning, and other key information about the local context, to prioritize pathways that provide greater dividends.

In applying the EAD for planning purposes, policy makers must consider the timing for when universal access should be achieved, population growth, regional development issues and priorities, and minimum tiers of access to be achieved within different regions. As the Honduras case highlights, the EAD can be a powerful tool for understanding benefits that accrue as households climb the tiers of access.

Given the benefits associated with electricity access, achieving the goal of universal access is critical to broader economic development. While SDG 7 presents the clearest connection to the EAD concept, the relationship between energy and development expands beyond basic access, which is reflected in the EAD calculation. The EAD framework demonstrates the relationship between energy access and quality education (SDG 4), reduced inequalities (SDG 10), climate action (SDG 13), and other development objectives.

The aggregate EAD figures in this report should be used as a conservative lower-bound estimate of electrification benefits. There remain many categories of benefits that for reasons of data availability remain unquantified here. As researchers drill down further in understanding additional benefit categories related to energy access—like how households use their financial savings, health improvements, time use changes outside of increased study time, increased commercial and industrial productivity, and broader community effects (see Section 4.2)—these additional benefits can be incorporated into relevant planning.

1. INTRODUCTION



1. Introduction

1.1

The benefits of energy access

Access to modern and reliable energy services provides myriad benefits. Many of these benefits are related to enhanced productivity, which increases opportunities for income generation for households and firms. Even when higher income does not result, modern energy may facilitate more efficient time use, and relief of drudgery, for example from solid fuel collection or hauling of water. Modern energy also enables new consumption opportunities that enhance well-being, ranging from consumption of information and entertainment to services and foods whose production require specific appliances. Energy is also foundational for improving the delivery of many basic public services on which people rely to meet fundamental development needs, including safeguarding of health in community clinics or hospitals, enhancement of learning opportunities for children attending schools, or in enhanced safety and protection from crime through public lighting.

These energy demands related to so many aspects of modern life have led some to dub energy the “golden thread” that connects economic growth, social equity, and environmental sustainability (United Nations, 2012). Yet today, one in six people worldwide live without any access to electricity (World Bank, 2015), while many more consume energy at very low levels, often from unreliable supplies (IEA, 2016; Nordhaus et al., 2016). About 40 percent of the global population relies on solid fuels and dirty technologies for lighting, cooking, and heating, exposing them to negative health, productivity, and environmental consequences (World Health Organization, 2014). These are shocking numbers, and the increasing consensus surrounding energy poverty has led to a global call to arms to tackle the problem, as evidenced most clearly in the establishment of the seventh Sustainable Development Goal, which endeavors to “ensure access to affordable, reliable, sustainable, and modern energy for all” by 2030.

As clear as the problem is, policymakers remain hamstrung by a lack of clarity in quantifying the gains – or dividends – that come with energy access. In terms of aligning politics and planning high-level budget priorities, better understanding of these gains can be critical to building momentum to deliver them. Such understanding is vital for governments in low- and middle-income countries that are striving to deliver economic development and opportunity to their people, for donors aiming to support those governments with focused programming, and for the many businesses, NGOs, community groups, and other institutions that help to implement energy access solutions. In addition, such information can aid decision-making related to what types of solutions deliver the greatest benefits, and in what contexts. For example, there is a vibrant debate today concerning the appropriateness of various types of off-grid solutions and how the benefits of these solutions compare to those offered by conventional grid extension. Similarly, questions abound concerning the relative importance of extending basic access to more people versus enhancing the access of those already served. Discussion of such questions requires analysis of how benefits and economic development can be maximized, as well as consideration of the distribution of those enhanced outcomes and the ethical dimensions of energy access.

This report describes an approach used to provide enhanced information on the nature of the energy access dividend (hereafter called the EAD). This report is not the first to address this problem: a previous report titled "Why Wait? Seizing the Energy Access Dividend" developed a framework for evaluating "the economic, social and environmental benefits that households and countries can expect through accelerated access to decentralized electricity, such as solar home systems and microgrids" (SEforALL and Power for All, 2017). The approach taken in this report uses the Why Wait framework as a starting point and extends it by including more impacts and leveraging new data pertaining to those impacts and to whom they accrue. This extended approach is applied to two Latin American country cases, Haiti and Honduras. In both settings, energy poverty continues to pose important challenges, but the nature of the problem is quite different. Haiti has the lowest rates of electricity access in the Western Hemisphere, while Honduras has much higher connection rates but mostly faces problems related to last mile connections and electricity quality. In fact, the contrasting nature of the challenge in these two settings provide a useful comparison that also helps to better demonstrate the value of EAD quantification.

1.2

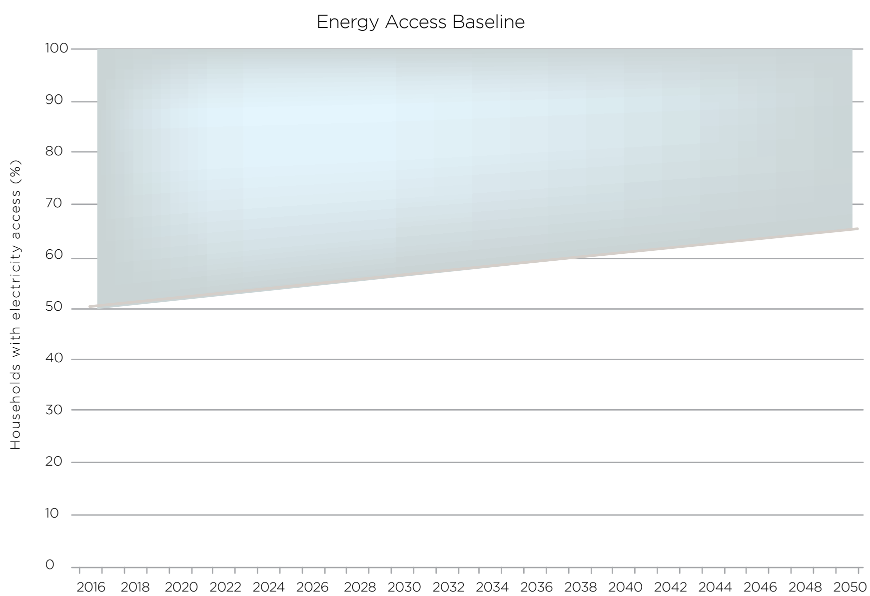
Defining the Energy Access Dividend

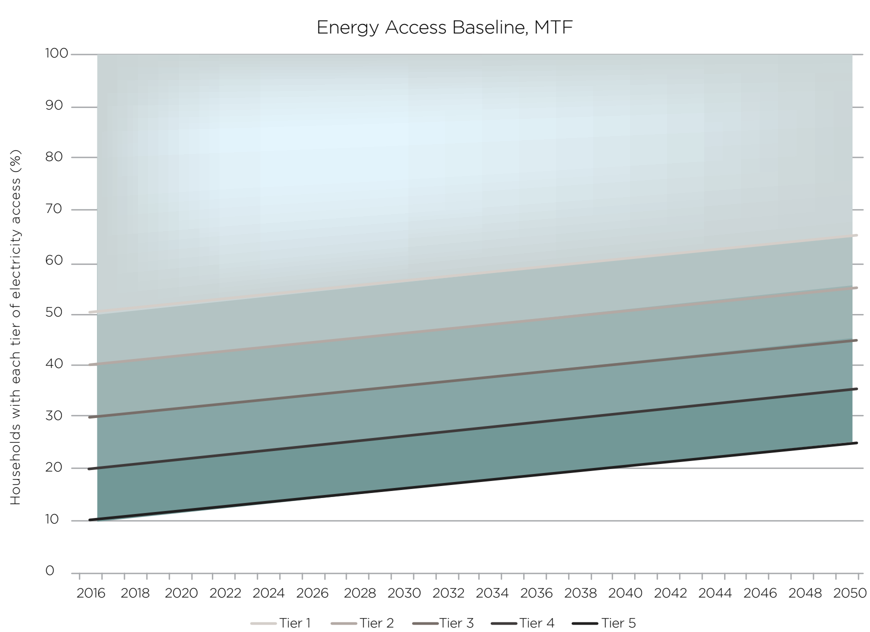
The conceptualization of the EAD originates from the idea of quantifying and valuing the opportunity costs of slow electricity transitions. During the time in which they do not have access to electricity, households miss out on opportunities to utilize electricity for productive or other benefit-generating ends. Thus, the EAD serves as a framework to calculate these forgone benefits over the course of a baseline, or "business-as-usual", electricity transition (Power for All, 2016; SEforALL and Power for All, 2017).

Figure 1 (top panel) depicts the population to which the EAD accrues graphically for a hypothetical case of access to basic electricity. As shown, the baseline rate of electricity access is 50 percent. By the end of the time horizon across which the EAD is calculated, access under "business-as-usual" expansion of coverage with connections has risen to 65 percent. The population that accrues the EAD over this time horizon, depicted in the shaded region in the graph, represents the unelectrified households in each year. In percentage terms, this population decreases over time as more people gain connections.

Later in the report, this basic definition of the EAD (the "basic" EAD) is extended to also encompass quality aspects related to electricity access (the "extended" EAD). That is, in this extended definition of the EAD, the forgone benefits associated with both lack of access to electricity and access to electricity that has quality or reliability deficiencies are considered. The concept of the Multi-Tier Framework (MTF) for characterization of energy access (Bhatia and Angelou, 2015), which is described further below in Section 1.3 is used to incorporate this quality aspect. For illustrative purposes, extending the simple case in Figure 1, the 50-65 percent of the population having access at baseline into tiers 1-5 could be subdivided (bottom panel), where the range again corresponds to evolution over time of the "business-as-usual" extension of energy access and quality. The more complete EAD then encompasses the foregone benefits experienced over the time horizon by (i) the 35-50 percent not having any access at all, and (ii) the 75-90 percent (inclusive of those unconnected) having less than the tier five (or highest quality) access.

Figure 1: Households accruing the energy access dividend (top), and by tier (bottom).





The EAD is not solely about population unconnected however, because simply identifying the unelectrified population offers little insight concerning the magnitude of forgone economic benefits. There are four key steps required for estimating the EAD. Step one concerns identification of the relevant categories of positive impacts associated with access to electricity and higher quality electricity. This step yields a qualitative conception of the lost opportunities from deficiencies in the supply of modern energy within a country. Step two then aims to quantify each of those types of impacts. For example, access to electricity provides benefits in the form of reduced use of alternative fuels such as kerosene. The forgone benefits in a particular year, from lack of access among unconnected people, can then be quantified in terms of the quantity of kerosene (e.g., in liters) that is displaced per person over the course of that year. Step 3 is the valuation or monetization of those quantified benefits. In the kerosene example, the expenditures on kerosene within unconnected households are used as a measure of the value of these forgone benefits, although a more complete conception would use the true shadow cost of that kerosene use, which would account for price distortions in the market for kerosene as well as the social and environmental externalities associated with kerosene use. Finally, in step four, the various economic benefits of enhanced energy access are aggregated together to produce the EAD estimate. To do so, the monetized benefits that households would enjoy with improved access are ascribed to them, for simple connections (in the basic EAD) and for the highest quality of access (in the enhanced EAD). To further aggregate these benefits consistently over the entire time horizon, the EAD is calculated as the sum of these benefits across the time horizon, discounted to reflect present values. In each EAD calculation presented in this report, the EAD for immediate access is estimated against the "business-as-usual" baseline rate of electrification.

The next section briefly summarizes the scope of the analysis, prior to the more detailed description of steps 1-4 that follows later in the report. This summary also identifies additional relevant impact categories that are not included in the quantitative analysis, for reasons such as lack of sufficient evidence, insufficient data, or particular challenges related to valuation of those impacts.

1.3

Identifying the components of the Energy Access Dividend

1.3.1
Economic benefits of new connections

The first benefits from electrification that households often experience come from the lighting transitions. Even with low energy capacity and limited duration of access throughout the day, households that gain access transition away from non-electric fuel sources for lighting such as biomass and kerosene. Importantly, lighting is often the main benefit for households attaining electricity access through non-grid solutions (e.g., micro-grid, solar home systems). Depending on the nature of the alternative fuels that are displaced, households often gain time and/or monetary benefits from this lighting transition. This report focuses on the financial savings households gain when transitioning from kerosene to electric lighting.

Second, members of households may alter the distribution of their time after gaining access to electricity for lighting. It is often argued that this will have positive implications for children's study habits, especially during evening hours. The literature relating electricity access, time spent studying, and education outcomes, however, provides mixed evidence regarding this benefit. Some studies find evidence of positive effects of electrification on educational attainment (Daka and Ballet, 2011; Lipscomb et al., 2013), while others find the opposite (Ismail and Khembo, 2015; Squires, 2015). This report focuses on changes in study time when data is sufficient to facilitate their measurement.

Reduced emissions encompass a third benefit related to the lighting transition. Burning biomass and kerosene for lighting emits climate-affecting pollutants such as carbon dioxide (CO2), black carbon (bc), methane (CH4), carbon monoxide (CO), nitrogen oxide (N2O), and organic carbon (oc); use of these fuels also often (but not always) releases more emissions than those released through the generation and use of electricity. As such, use of electricity for lighting often reduces emissions. This report focuses on the emissions reductions resulting from households transitioning from kerosene to electric lighting.

In addition to lighting, households typically use basic electricity access for cell phone charging. Without private electricity access, households with cell phones often pay to charge them outside their homes, sometimes at high cost and difficulty. Thus, electricity can provide time and financial savings to households. This report focuses on the reductions in household expenditures incurred for cell phone charging outside the home.

1.3.2
Tiered framework of electricity access

Consideration of benefits beyond those from simple connections that primarily provide lighting and phone charging benefits requires a framework that captures the quality, reliability, and safety of electricity access. The multi-tier framework (MTF) developed by the Energy Sector Management Assistance Program (ESMAP) unit of the World Bank (Bhatia and Angelou, 2015) is a useful tool for considering benefits of this nature. The MTF framework allows examination of the differential benefits accruing to households across six tiers (0-5) of access, where higher tiers indicate “better” access to electricity. The framework incorporates seven dimensions of access to characterize the energy access tier: capacity, duration, reliability, quality, affordability, legality, and health/safety. Figure 2 depicts the concept of energy tiers, focusing on the dimensions of capacity and duration.

In tier 0, households do not have electricity access and must rely on other sources (candles, kerosene, biomass, or use of outside electricity) to meet their energy needs. In tier 1, households have connections with capacity only to power a single light bulb and charge a cell phone, and that provide electricity only a few hours per day. In tier 2, households can power small appliances like radios or fans in addition to lighting and cell phone charging. Households with tier 3 access have moved beyond electrification via basic solar products and may be electrified through grid connections, microgrids, or larger solar home systems. These larger systems provide capacity, quality, reliability, and duration improvements, and allow the powering of increasingly electricity-intensive appliances or assets for up to eight hours of electricity per day. Grid-based electricity facilitates access to tiers 4 and 5, which provide additional capacity and a longer supply of power (a minimum of sixteen hours per day for tier 4, and twenty-three hours per day for tier 5).

While the dimensions of electricity capacity and duration enter into the MTF framework across all tiers, the other five dimensions of energy access become relevant in tiers 3 through 5. Reliability, characterized by service disruptions differentiate between tier 4 (maximum of 14 disruptions per week), tier 5 (maximum of 3 disruptions per week), and all other tiers (weekly disruptions not incorporated). Quality differentiates between tiers 1-3, in which electricity quality may prevent the use of some high-voltage appliances, and tiers 4-5, in which all appliances can be powered. Affordability differentiates between tiers 1-2, which have no affordability component, and tiers 3-5, which indicate that households must pay a maximum of 5 percent of yearly income to access 365 kWh. Legality differentiates between tiers 1-3, which have no legality component, and tiers 4-5, which stipulate that electricity bills are paid to the utility or authorized seller. Finally, health/safety differentiates between tiers 1-3, which have no health/safety component, and tiers 4-5, which include access that is free of accidents.

Figure 2: Multi-tier framework for energy access.

			TIER 0	TIER 1	TIER 2	TIER 3	TIER 4	TIER 5
ATRIBUTES	1. Peak Capacity	Power capacity ratings (in W or daily Wh)		Min 3 W	Min 50 W	Min 200 W	Min 800 W	Min 2 kW
				Min 12 Wh	Min 200 Wh	Min 1.0 kWh	Min 3.4 kWh	Min 8.2 kWh
		OR Services		Lighting of 1,000 lmhr/day	Electrical lighting, air, circulation, television, and phone charging are possible			
	2. Availability (Duration)	Hours per day		Min 4 hrs	Min 4 hrs	Min 8 hrs	Min 16 hrs	Min 23 hrs
		Hours per evening		Min 1 hrs	Min 2 hrs	Min 3 hrs	Min 4 hrs	Min 4 hrs
	3. Reliability						Max 14 disruptions per week	Max 3 disruptions per week of total duration <2hrs

Adapted from the World Bank/ESMAP, Beyond Connections: Energy Access Redefined, 2015.
https://www.seforall.org/sites/default/files/2019-06/SEforALL_IEP_2019.pdf

1.3.3
Benefits of improved connections

As households progress through the MTF tiers described above, they will experience different types of benefits. Ownership and use of energy-consuming appliances and assets represents a large category of potential benefits households may enjoy with higher-quality electricity access. These electricity-using assets may provide a variety of benefits. For example, radios and televisions provide both leisure and informational benefits, fans are used for space cooling, and refrigerators enable food storage and preservation. This report focuses on ownership of these four assets and estimates the consumer surplus obtained from each asset in the EAD calculation.

Finally, electricity for productive use is an increasingly relevant benefit as households progress to higher energy tiers. Households with more reliable, higher capacity electricity access begin to use electricity as an input to income generation. As such, they may incur income losses when they experience unexpected interruptions in access. Because reliability and duration increase as a household progresses through the tiers, these unexpected service interruptions and associated losses occur with lower frequency at the highest tiers. This report focuses on the reductions in income loss that households experience as they transition to higher tiers. Of course, individual households are not the only beneficiaries of increased and improved electricity access; there are also benefits to firms. While firm-level benefits are not the focus of this report, they are an important category of potential benefits attributable to increased electricity access.

In summary, households experience benefits from electricity access both from acquiring initial, basic connections, and during their transition towards higher energy tiers. Table 2 summaries the benefits included in estimates of the EAD.

Table 2: Benefits across tiers

	Tier 1	**Tier 2**	**Tier 3**	**Tier 4**	**Tier 5**
Included	▪ Savings of alternative lighting fuels • Climate-forcing emissions (CO_2; black carbon) • Phone charging • Radio ownership	▪ Additional phone charging ▪ Fan ownership ▪ Refrigerator ownership	▪ Study time ▪ Television ownership ▪ Refrigerator ownership		▪ Improved reliability
Excluded	• Study time • Health benefits of reduced emissions • Safety • Increased land values	▪ Changes in time allocation ▪ Additional health benefits ▪ Additional safety ▪ Increased land values	▪ Improved reliability ▪ Additional productive use ▪ Changes in time allocation ▪ Additional health benefits ▪ Additional safety ▪ Increased land values	▪ Improved reliability ▪ Additional productive use ▪ Changes in time allocation ▪ Additional health benefits ▪ Additional safety ▪ Increased land values	▪ Additional productive use ▪ Changes in time allocation ▪ Additional health benefits ▪ Additional safety ▪ Increased land values

1.3.4 Benefits excluded from calculation

While this study attempts to include many of the benefits of both initial and extended electricity access in calculations of the EAD, several categories of potential benefits are excluded from the analysis (Table 1), either due to mixed evidence or data limitations. First, while a first attempt is made at valuing improved reliability through reductions in income loss due to unexpected interruptions in access (albeit only for tier 5), further productive benefits of electricity access are omitted from the calculation. For example, increased productivity for small businesses, agriculture, or in in-home production are not included in the quantification of the EAD. Due to the absence of detailed data on electricity use for businesses in the MTF surveys on which the study relies, there is insufficient justification for quantification of additional productive benefits at this stage.

Second, time use changes (outside of study time) associated with energy access are excluded from the analysis. Data availability is insufficient to quantify changes in household and income-generating work patterns, leisure time, and time spent on communications (SEforALL and Power for All, 2017). Furthermore, clear links between electricity access and many of these time use changes have not been identified in the broader academic literature.

Third, health benefits associated with electrification are excluded from the EAD calculation. Heating and cooling, changes in emissions, and refrigeration of medication are all mechanisms that could lead to improved health outcomes. Again, data quality, particularly the challenge of cleanly identifying the specific effects of electricity versus other confounding factors, render inclusion of health difficult in the EAD calculations.

Fourth, community benefits associated with electrification including safety and increased land value are not included in the EAD calculation. Electrified communities have more lights at night, increasing safety and security. Additionally, economic development spurred by electricity use in home or small-industry production can increase the value of local holdings such as land (Pueyo et al., 2013).

Finally, it is crucial to highlight that the costs of improved energy access are not included in these calculations. As such, the EAD estimates represent gross benefits, and does not provide guidance on the net value of different approaches to closing the gap in energy access. Rather, they only point to the forgone benefits from not pursuing those approaches. This is important, because the costs of strategies to accelerating coverage with different tiers of access (e.g., tier 1 vs. tier 3 or 5) are likely to be very different, and will also depend on contextual factors such as population density, the geographic appropriateness of decentralized solar options, etc. Estimating these costs is beyond the scope of this analysis but warrants a careful study of its own.

1.4 Overview of report

The remainder of the report is organized as follows. Section 2 begins with a presentation of the prior EAD framework and methods as applied to Bangladesh, Kenya, and Ethiopia (SEforALL and Power for All, 2017). It then discusses several basic modifications to the approach and applies that modified approach to valuation of the basic EAD in Haiti and Honduras. The following section expands this methodology to consider the quality of electricity access, incorporating the aspects related to the different tiers of access. Use of these extended methods is demonstrated for the case of Honduras, for which MTF survey data is available. Section 4 discusses the EAD results for Haiti and Honduras, explores potential further extensions of this framework, and concludes with recommendations for policymakers and researchers, which emerge from this analysis.

2. THE ENERGY ACCESS DIVIDEND FROM NEW ELECTRICITY CONNECTIONS

2. The Energy Access Dividend from new electricity connections

2.1

What is the Energy Access Dividend from enhanced energy access?

As described in the previous section, energy access provides a diversity of economic benefits, and quantifying the potential gains of accelerating access using a consistent framework is a significant challenge. The EAD discussed in this report is not a new concept, but rather an expansion of the framework and methodology previously demonstrated for three countries – Bangladesh, Kenya, and Ethiopia – in a recent study (SEforALL and Power for All, 2017). That report enumerated thirteen qualitative categories of benefits derived from obtaining electricity access, and partially quantified four of them: (i) savings on household lighting expenditures, (ii) savings on cell phone charging outside the home, (iii) reduced climate change emissions, and (iv) changes in time spent studying. These four benefits were judged to represent a potential bundle of benefits that households would enjoy from obtaining basic connections. For the most part, the approach did not capture differences in the EAD from basic connections versus higher quality access (e.g., tier 1 access compared to tier 5 access)[3]. That is, the EAD described in the report was essentially the same for households sourcing energy from small-capacity distributed systems enabling 4 hours of electricity per day and for those with 24 hour service from a high-capacity grid connection. This issue will be revisited in Chapter 3 of this report, in the context of considering the value of transitioning beyond basic (tier 1 level) connections.

Indeed, because the EAD estimate in the aforementioned analysis only pertains to basic connections and only includes a limited set of energy access benefits, its authors argued that it represents a lower bound on the value of accelerated energy access. Nonetheless, the EAD and several specific categories of benefits were judged to be significant. For example, savings of kerosene and cell phone charging expenses in Bangladesh over a nine year period

3. In the EAD calculations for Bangladesh, Kenya, and Ethiopia, there is some differentiation of the benefit calculation with regard to saving on lighting expenditures. Households that could gain more reliable connections were assumed to reduce non-electricity fuel consumption 1.2 to 2 times more than those who gaining only a basic connection (SEforALL and Power for All, 2017)
(SEforALL and Power for All, 2017).

were estimated to reach $2.2 billion dollars; the additional study time for children in Kenya over a seven year period was 2.3 million hours; and the emissions avoided in Ethiopia over a one year period were equivalent to 1.2 percent of Ethiopia's annual emissions. The different time horizons reported for each country have to do with the approach used in the analysis, which pegged the time horizon for the analysis to (likely aspirational) government targets for universal energy access.

Of course, this argument that the EAD represents a lower bound on the value of connections also rests on assumptions about the specific gains that electricity connections provide. For some types of benefits (specifically lighting, emissions, communication, and asset ownership), the evidence from previous research is stronger than it is for others (specifically education, time use changes, economic development, productive use, and health)[4].

The impacts of electrification on lighting, emissions, and communication (cell phones) are perhaps the most consistent throughout the academic literature. Lighting is a main use of electricity, with even low-quality access (i.e., tier 1) able to provide some lighting benefits (Komatsu et al., 2011). When households gain access to electricity, they often shift their primary lighting fuel sources away from candles, kerosene, and biomass, although the transition to electric lighting is often not complete. That is, while households reduce reliance on non-electric fuels, consumption does not drop to zero, as households may practice fuel stacking or continue to use non-electric fuel if their electricity access is unreliable (Komatsu et al., 2011; Lee et al., 20106). Reductions in non-electric fuel dependency are often accompanied by improved indoor air quality, as electricity burns cleaner than kerosene and biomass fuels. Barron and Torero (2017) and Lenz et al., (2017) test this in El Salvador and Rwanda, respectively, finding that electrified households have lower concentrations of PM2.5 and report improved air quality after electrification.

Electrification can also yield communication benefits, which are most commonly classified in the literature as the spread of access to cell phones and private cell phone charging. Once electrified, even with low tiers of access, households can charge their phones at home instead of seeking charging options among neighbors or in the market (Komatsu et al., 2011). While more difficult to quantify than saved expenditures on cell phone charging, there is also evidence of improved and easier communication among electrified households (Lenz et al., 2017). Households also invest in electricity-using assets once they obtain a high enough tier of access. Radios, televisions, fans, and refrigerators are among some of the most frequent assets owned by newly electrified households (Gustavvson and Ellegard, 2004; Lee et al., 2016).

The relationship between electricity and other potential benefits such as education, time use changes, economic development, productive use, and health are less clear in the literature. While many studies find a relationship between improved educational attainment or increased study time and electrification (Grogran, 2016; Gustavsson and Ellegard, 2004; Komatsu et al., 2011; Lipscomb et al., 2013), others find a more ambiguous (Lenz et al., 2017) or even negative (Squires, 2015) relationships. In Honduras, Squires (2015) finds evidence of reductions in schooling completion among children in electrified municipalities, suggesting that outside employment options for students themselves or older family members could be a mechanism that explains this somewhat unexpected result.

4. Table 19, in Appendix D, summarizes some of this literature on benefits of electrification. Importantly, Table 19 is intended to provide an introductory overview to the evidence from the literature; it is neither comprehensive nor systematic.

The relationship between electricity and other time use changes are also somewhat ambiguous in the literature. There is some evidence of increased employment (Lipscomb et al., 2013); however, these benefits are often found just for women and not for men (Grogan & Sadanand, 2013; Squires, 2015). Similarly, there are few studies examining the productive benefits of electrification. One such study by Lenz et al. (2017) finds no evidence of increased income generating activity as a result of electrification. Nevertheless, Lipscomb et al. (2013) argue that there is a strong relationship between electrification and economic development in Brazil, finding sizable increases in housing values and the human development index (HDI) as a result of expanded electrification.

Finally, there are few studies in the literature that clearly outline a causal relationship between electricity access and health. Barron and Torero's 2017 study in El Salvador is an exception. Utilizing a randomized design in which some households were encouraged to connect to the electric grid, they find evidence of improved respiratory health among young children in electrified households, suggesting there may be health benefits associated with electricity access.

2.2

Calculating the EAD for new, basic access

The approach taken here to calculating the EAD for new and basic access takes as its starting point the initial EAD framework (SEforALL and Power for All, 2017)[5]. Along the electricity transition pathway, households benefit from obtaining access to electricity; however, households not connected under the "business-as-usual" electrification trajectory miss out on these benefits until they become connected. Thus, the EAD calculation for new and basic connections contains three important pieces of information: (i) estimates of the benefits that a household experiences when it gains a basic tier 1 connection to electricity, (ii) the projected number of years (time horizon) over which these gains are calculated; and (iii) projections of the number of households lacking this basic electricity access under the "business-as-usual" rate of electrification, in each year of the time horizon.

As mentioned previously, this analysis of the basic EAD includes the same four categories of benefits as the original EAD report: (i) reductions on expenditures for non-electric fuels (primarily kerosene), (ii) reductions on expenditures for cell phone charging outside the home, (iii) changes in study time among children, and (iv) reductions in emissions associated with the consumption of dirty fuels. Data on kerosene and phone charging expenditures are used to estimate the savings that households experience in shifting to electricity, acknowledging that the prices implied in these calculations may not represent the true economic costs of those resources, due to market distortions (e.g., subsidies or taxes levied in kerosene and on commercial consumers of electricity).

The non-financial benefits to the household and society at large—emissions and study time—are more challenging to incorporate into the EAD calculation. With respect to reduced climate forcing from reduced kerosene use, six pollutants of interest are carbon dioxide (CO_2), black carbon (bc), methane (CH_4), carbon monoxide (CO), nitrogen oxide (N_2O), and organic

5. The equations used to model the EAD are available in Appendix A. Note that while the same generalized model presented in Appendix A is applicable for both this simple EAD as well as the extend EAD developed in Section 3, the calculations differ in the benefits and tiers included.

carbon (oc) (Jeuland et al., 2018)[6]. This report follows the methods outlined in Jeuland et al., (2018), but readapts them to apply to the energy transition context, rather than the cookstove space. Emissions factors for each pollutant are multiplied by their global warming potentials (with CO2 normalized to one), taking into account the differing time horizons of environmental impact of each pollutant (Jeuland et al., 2018; Shindell, 2015). These emissions are multiplied by the reduction in kerosene consumption and valued using the social cost of carbon (Jeuland et al., 2018; Nordhaus, 2017). For valuing gains in study time, the model again follows the prior EAD model in first calculating gains in study time (SEforALL and Power for All, 2017) and then builds upon approach by assigning monetary value to this time using a shadow value of time that is half the wage rate for unskilled labor (Whittington and Cook, forthcoming).

The overall EAD is calculated by summing the net benefits forgone each year under business as usual, i.e., the foregone benefits from the share of without connections, and then discounting these at a rate of 12 percent (IDB, 2018)[7]. By definition, the EAD goes to zero once universal access is achieved. If, however, universal electrification is not projected to occur by 2050 (as is the case with Haiti), the EAD only accrues up this date, given the high uncertainties with extending the projections of electrification, population growth, and other parameters relevant to the EAD calculation, over a longer time horizon[8]. As mentioned above, this EAD calculation is likely a lower bound on these forgone benefits, though there is only limited empirical evidence that basic electricity access delivers benefits other than those included here.

Data. To estimate the EAD for basic electricity access, information for determining these benefits – household energy consumption, expenditure, time use – and on electrification trends over time is needed. Unfortunately, the same countries that have made the least progress towards universal electrification are also most often lacking in the data needed to support high quality EAD calculations. As such, whenever possible (e.g., for reported rates of electricity access), consistency across multiple sources is checked to improve confidence in the estimates[9]. Data from a variety of sources is used, including country-specific reports, the academic literature, other data sets, and for Honduras, analysis of the detailed data available in the recent, nationally representative, multi-tier framework (MTF) survey of households in that country (Bhatia and Angelou, 2015; World Bank and ESMAP, 2018). Projections of electricity access and population growth are informed by data from the IEA and World Bank (IEA and World Bank, 2017; World Bank, 2018a), extrapolated forward based on linear trends over the recent past[10]. Where data are especially scarce (this is particularly relevant in the Haiti analysis), the report aims to explain underlying assumptions as clearly as possible. For Honduras, relevant parameters were extracted from the MTF survey data, using cross-sectional regressions of the relationship between electricity access and the benefit outcomes of interest, controlling for the gender and age of the household head, household size, number of children, yearly

6. While carbon dioxide (CO2), black carbon (bc), methane (CH4), carbon monoxide (CO), and nitrogen oxide (N2O) all contribute to global warming potential, organic carbon (oc) contributes to cooling.

7. The application of a 12 percent discount rate in this case may not be appropriate. Development banks typically use such high discount rates in order to properly account for the opportunity costs of capital investment, but an alternative approach is to discount consumption equivalents using a social consumption discount rate (typically estimated in the range of 3-5 percent based on a Ramsey discounting approach), and to separately account for the scarcity of capital when alternative investments are displaced. In addition, it is worth pointing out that this analysis is not a cost-benefit analysis of investments aimed at capturing the EAD (where the source of funds for capital outlays would need to be considered carefully), but rather of the largely consumption-related benefits of energy access. Given these concerns, results that rely on a lower, 5 percent discount rate, as well as undiscounted results, are also presented.

8. For example, the World Bank population projections are only available through 2050 (World Bank, 2018a).

9. A table outlining all parameters used in the EAD calculations as well as their sources is available in Appendix B.

10. Alternative (non-linear) projections of electrification transition pathway could also be used to establish a baseline for comparison.

income, and a household asset index; these parameters were estimated separately for rural and urban populations. Coefficients that were significant at or below the 10 percent level were used to parameterize the model. If the regression-based estimates did not align with trends in the literature, benefits were imputed using mean effect sizes estimated in the literature and baseline characteristics from the Honduran household survey data.

2.3

Calculating the simple Energy Access Dividend for Haiti

2.3.1
Electricity access context in Haiti

Unique compared to its Caribbean and Latin American counterparts, electricity access among Haitian households is extremely low. The World Bank reports that only 39 percent of the Haitian population had access to electricity in 2016, leaving over 6.6 million out of Haiti's 10.8 million people unelectrified (World Bank, 2018b). In addition, the rate of electrification in Haiti is slow with only three percent of the population gaining access between 2009 and 2016. Continuing at this rate, Haiti would not achieve universal electrification until 2150.

These national estimates obfuscate stark differences in electricity access among rural and urban populations. Although limited data is available to determine precise access rates among Haiti's rural and urban population, the World Bank reports that 65 percent of the urban population has electricity access. Access is thus extremely limited in rural areas of the country (IEA and World Bank, 2017). Furthermore, reported access rates vary substantially from year to year (World Bank, 2018b). In general, it seems that year-to-year fluctuations in the estimates of electricity access in Haiti may be unreliable, though most estimates of the connection rate range between 20 and 40 percent (Studi and Hatch, 2018).

It is also worth noting that Haiti does not have a single centralized grid. Instead, Electricité d'Haïti (EDH), which serves as the only utility in the country, operates a centralized grid in Port-au-Prince. Outside of the capital city, EDH operates 10 smaller, regional grids for urban areas and about 30 small grids, which operate at the village level (Stuedi and Hatch, 2018). These operations leave a majority of Haitians, particularly in rural areas, without access to grid-based electricity. In response, there has been an increase in independent micro-grid activity in Haiti, although this electrification approach also faces challenges including local buy-in, daily operations and management, and infrastructure protection (Stuedi and Hatch, 2018).

2.3.2
Indicators and data for EAD calculation, Haiti

This section summarizes the indicators and data sources used to calculate the EAD for Haiti. Additional details are provided in Appendix B (Table 8). Given the uncertainty in differentiating access and forgone benefits separately for Haiti's rural and urban population, only a national-level EAD is calculated.

Energy access, population, and household size: As discussed above, the World Bank reports Haiti's annual electrification rates, which are used to estimate yearly progress under "business-as-usual". Noting the slow trend in electrification, the EAD theoretically could extend far into the future; the analysis here is limited to the 2016-2050 period, as discussed above. Population changes are incorporated into the analysis; a constant average household size of 4.4 individuals over time is assumed to estimate the number of unelectrified households in each year (MSPP, 2013; World Bank 2018a, 2018b).

Lighting expenditures: Kerosene, biomass, and candles are the primary sources of fuel for lighting in Haiti. The calculation of the simple EAD for Haiti takes a conservative approach to estimate reduced lighting expenditures by multiplying the price of kerosene in Haiti by the difference in kerosene consumption between tier 0 and tier 1 households calculated from household survey data from Honduras (World Bank and ESMAP, 2018). This implies a reduction of kerosene expenditures of 96 Haitian gourdes ($1.35 USD) per month.

Cell phone charging: While rates of electrification in Haiti are low, cell phone ownership and use are relatively high, such that the cell phone charging benefit is potentially quite high. Given a lack of data on cell phone charging expenditures in Haiti, the analysis again relies on adapting household survey data from Honduras (World Bank and ESMAP, 2018) to estimate the potential savings. These cell phone charging savings are estimated at 704 Haitian gourdes ($9.92 USD) per year.

Emissions: To calculate the reductions emissions that result from universal electrification (carbon dioxide (CO_2), black carbon (bc), methane (CH_4), carbon monoxide (CO), nitrogen oxide (N_2O), and organic carbon (oc)), kerosene consumption savings in liters are calculated for Haiti based on the difference in kerosene consumption between tier 0 and tier 1 households in the Honduran household survey data (World Bank and ESMAP, 2018). These reductions amount to 23.6 liters per year. This decreased kerosene consumption is then converted into their global warming potential and valued at the social cost of carbon following the method outlined in Jeuland et al. (2018).

Study time: Given the inconclusive effect of electricity on study time identified in the literature and the lack of Haiti-specific reporting or data to verify a relationship, this benefit is not included in the basic EAD calculation for Haiti.

2.3.3
Estimating the simple Energy Access Dividend for Haiti

The EAD calculation for Haiti estimates the forgone benefits from lack of access to basic electricity that are implied by the “business-as-usual” electrification trajectory, through the year 2050. In Haiti, the present value of this EAD amounts to 30 billion gourdes, or $422.5 million USD (the total undiscounted benefits are 128.8 billion gourdes, and the present value using a discount rate of 5 percent is 55.5 billion gourdes). Figure 3 shows the time profile of this cumulative EAD. The EAD calculated in the first year (2016) amounts to 3.2 billion gourdes. Given that the benefits included in this EAD calculation include only those accrued for basic electricity access, this estimate of 3.2 billion gourdes should be considered a lower bound for the benefits that would be provided by universal electrification in 2016, or for the present value of benefits of 30 billion gourdes over the period 2016-2050.

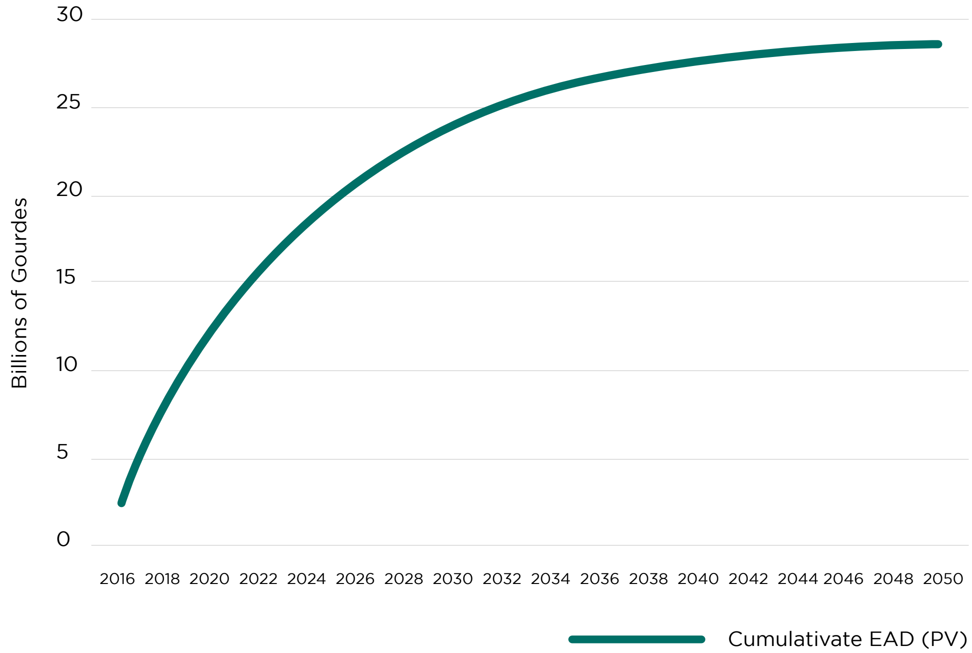


Figure 3: EAD for basic universal electrification, Haiti

While this overall EAD calculation indicates that a rapid intensification in electrification in Haiti would have substantial dividends, the values associated with the three main categories of benefits—lighting expenditures, emissions, and cell phone charging expenditures—are not evenly distributed across benefit type. If universal connections forgone under "business-as-usual" were provided immediately, the dividend accruing from savings of lighting expenditures would represent 54 percent of the total benefit; the dividend accruing from savings on cell phone charging expenditures would be 33 percent of the total benefit; and the dividend accruing from combined emissions would be about 13 percent of the total benefit (Table 3). Furthermore, the cumulative emissions savings include about 6.6 million tons.

Table 3: Simple EAD by benefit type, Haiti

Cumulative Dividend		**Percent of total**
Lighting expenditure (billion gourdes)	16.24	54.2 percent
Combined emissions (million tons)	6.58	
Combined emissions (billion gourdes)	3.79	12.6 percent
Cell phone expenditure (billion gourdes)	9.93	33.1 percent
Dividend in 2016		
Lighting expenditure (billion gourdes)	1.74	54.2 percent
Combined emissions (million tons)	0.19	
Combined emissions (billion gourdes)	0.41	12.6 percent
Cell phone expenditure (billion gourdes)	1.06	33.1 percent

2.4

Calculating the simple Energy Access Dividend for Honduras

2.4.1
Electricity access context in Honduras

In contrast to Haiti, Honduras has high levels of electrification. In Honduras, access to electricity reached 82 percent in 2016, leaving around 1 million people without access to electricity (World Bank and ESMAP, 2018). The challenge facing Honduras is that many of the remaining unelectrified households live in remote, rural communities. Recent data collection efforts by the World Bank and ESMAP (2018) suggest that while only 2 percent of urban Honduran households lack electricity access, nearly 30 percent of rural Honduran households are unelectrified, and policy solutions for accelerating basic access must therefore be directed towards rural populations. Grid expansion, used to achieve most prior connections, may be a relatively expensive approach for reaching these last-mile households, relative to non-grid and decentralized renewable electricity solutions.

2.4.2
Indicators and data, Honduras

This section summarizes the indicators and data sources used to calculate the EAD for Honduras. Specific parameters for the EAD calculated for Honduras, along with their estimation, are presented in Appendix B (Table 9). For the purposes of comparison with the situation in Haiti, while this section calculates the EAD benefits for rural and urban households separately, one EAD for basic electrification is presented, which is the weighted sum across rural and urban households.

Energy access, population, and household size: As discussed above, household-level survey data is used to characterize electricity access in Honduras in 2016. Annual electrification rates reported by the World Bank for urban and rural areas are combined with the 2016 coverage rates to estimate yearly progress under "business-as-usual" (2016-2038). This time horizon is used as it represents the entire electrification transition for Honduras under "business-as-usual". In urban areas, universal electrification is reached in 2028, and in rural areas, universal electrification is reached in 2038. Population changes are incorporated into the analysis; a constant average household size of 4.5 individuals over time is assumed to estimate the number of unelectrified households in each year (World Bank and ESMAP, 2018).

Lighting expenditures: Unelectrified households in Honduras primarily use kerosene to meet their lighting needs. By comparing households with and without basic electricity access, controlling for household demographic and economic characteristics, the difference in kerosene consumption for these two types of households can be estimated[11]. This consumption reduction is valued at the price of kerosene in Honduras and is used in the EAD calculation to represent the lighting

11. Given the enhanced data availability in Honduras, the parameters used in the Honduras EAD are more carefully estimated than is possible with the data for Haiti. That is, the household-level MTF data allows for regression analysis of electricity access on lighting expenditures, controlling for other household-specific characteristics. This same analysis is used to estimate changes in kerosene consumption and expenditures on cell phone charging. Within each of these regression models, any non-responses are treated as zeros. While these regressions fall short of best practice for identifying a causal link between electricity access and lighting expenditures, they are arguably more relevant than the literature-based parameterization of the Haitian EAD. Accordingly, direct comparisons of the Haiti and Honduras EAD calculations should be considered with caution.

expenditure savings that unelectrified households could enjoy if Honduras obtained universal access to basic electricity. This benefit is estimated to be 32.4 Honduran lempiras (or $1.35 USD) per household per month[12.]

Cell phone charging: Given the prevalence of cell phones in Honduras—estimated to be two cell phones per household—the avoided expenditures for cell phone charging outside the home could be substantial (World Bank and ESMAP, 2018). By comparing the expenditures on phone charging outside the home for households with and without access to basic electricity, controlling for household demographic and economic characteristics, the cell phone charging benefit for the EAD calculation can be estimated. Among the Honduran sample, this savings is 238 lempiras ($9.91 USD) per household per year.

Emissions: By comparing the kerosene consumption reported by households with and without basic electricity access, controlling for household demographic and economic characteristics, the difference in kerosene consumption for these two types of households can be estimated. Among the Honduran sample, this reduction in kerosene consumption is about 24 liters per year per household. This decreased kerosene consumption is converted into emissions reductions for carbon dioxide (CO2), black carbon (bc), methane (CH4), carbon monoxide (CO), nitrogen oxide (N2O), and organic carbon (oc) using methods outlined in Jeuland et al. (2018). In this context, the reductions in kerosene usage we calculate are related to transitions in lighting fuel from kerosene to electricity. We do not consider emissions changes related to firewood use as we do not include cooking transitions in the EAD calculation[13.]

Study time: Households may redistribute their time after gaining access to electricity, leading to changes in study habits among children. Analyzing the Honduran household data, however, there is no evidence of an effect on education from basic energy access, as measured by children's study time, among girls or boys. Given the inconclusive effect of electricity on study time identified in the literature and in the MTF data, this benefit is not included in the basic EAD calculation for Honduras.

2.4.3
Estimating the simple Energy Access Dividend for Honduras

The EAD calculation for Honduras estimates the forgone benefits from lack of access to basic electricity that are implied by the "business-as-usual" electrification trajectory, through the year 2038 (when universal electrification would be achieved). In Honduras, the present value of this EAD amounts to 1.3 billion lempiras, or $54.2 million USD (the total undiscounted benefits are 2.7 billion lempira, and the present value using a discount rate of 5 percent is 1.8 billion lempira) (Figure 4). The EAD calculated in the first year (2016) is 0.2 billion lempiras ($8.4 million USD). While this value may not represent a substantial EAD for basic energy access in Honduras, it is important to remember that the country begins its electrification transition at high rates of electrification and that the benefits included in the calculation include only modest reductions in expenditures for lighting and cell phone charging and in emissions.

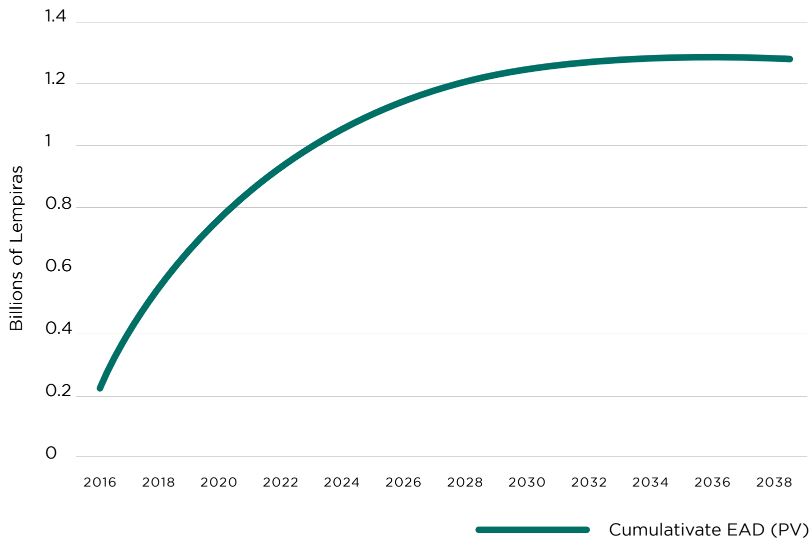
This figure is comparable to the EAD calculated for Haiti because it incorporates the same benefits: reduced lighting and cell phone charging expenditures and reductions in climate-affecting emissions

12. An exchange rate of 24 Honduran lempiras to $1 USD is used throughout this report.

13. In this report, we focus on the role of electricity in transitioning across lighting fuels rather than across cooking fuels. While approximately 15 percent of Honduran households in the MTF sample indicated use of electricity for cooking in the previous year, only 6 percent of households cited electricity as the only cooking fuel. Given the prevalence of fuel stacking demonstrated in these data and elsewhere in the literature, we do not include a cooking dividend in our EAD calculation.

valued using the social cost of carbon. A comparison across these two cases demonstrates that the EAD for basic universal electrification is much larger for Haiti than it is for Honduras. This is unsurprising as Haiti starts the electrification transition at 39 percent access, whereas Honduras starts at 82 percent access. Furthermore, the transition in Haiti is calculated over a longer period of time—34 years for Haiti compared to 22 years for Honduras. Simply put there are more dividends to be had from accelerated access to basic electricity in Haiti than in Honduras.

Figure 4: EAD for basic universal electrification, Honduras

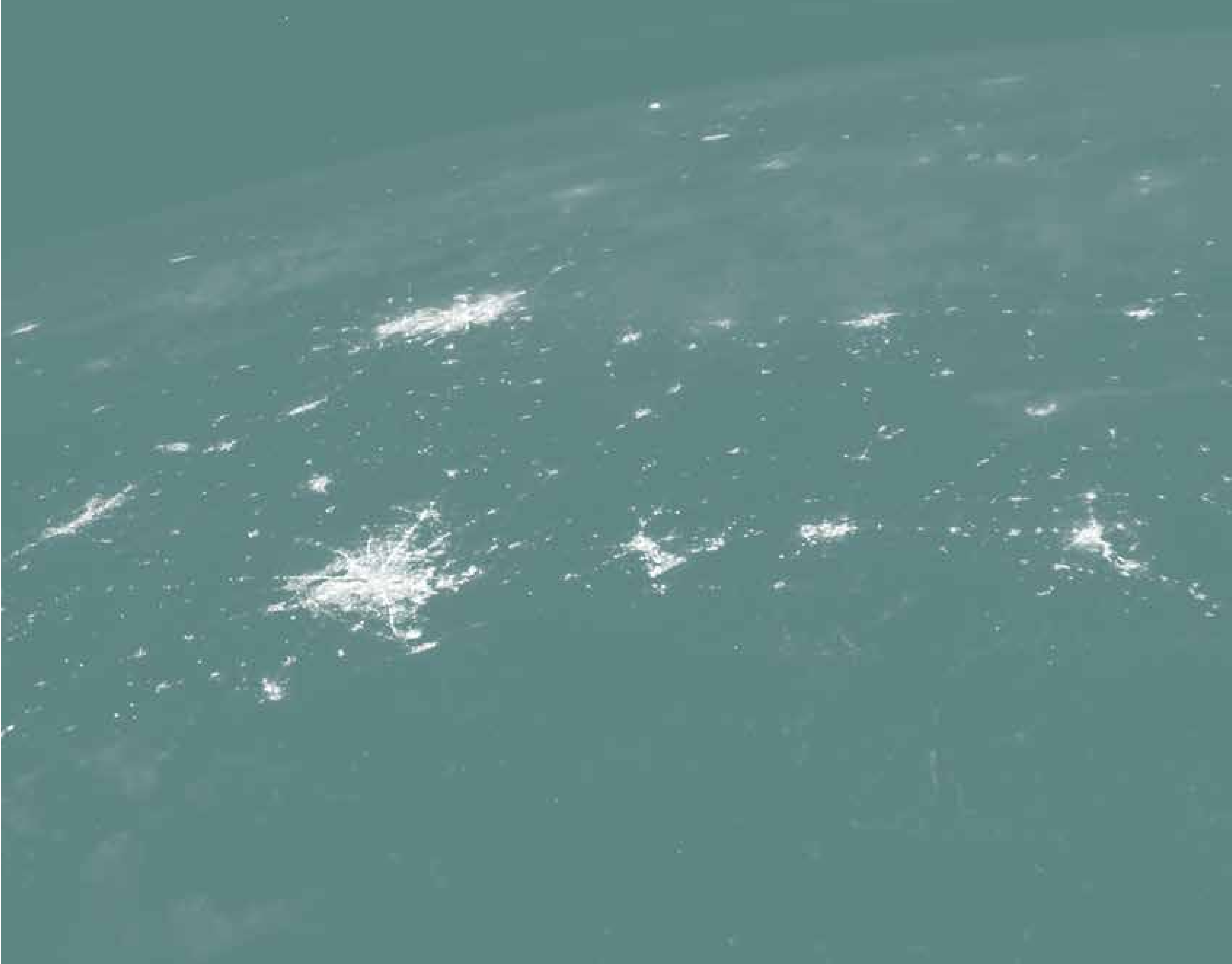


This overall EAD calculation suggests that while Honduras would benefit from a more rapid electrification process, the transition to universal, basic electrification along the "business-as-usual" pathway proceeds at a pace that would achieve universal electrification in less than two decades. Given this, there is a relatively modest loss of basic electrification benefits in the country. Considering the distribution of benefits across lighting, cell phone charging, and emissions (Table 4), if Honduras were to achieve universal electrification immediately rather than in 2033, reduced climate-forcing emissions from burning kerosene would constitute about 13 percent of the EAD; reduced cell phone charging another 33 percent; and the remainder resulting from reduced expenditures on kerosene for lighting.

Table 4: Simple EAD by benefit type, Honduras

Cumulative Dividend		**Percent of total**
Lighting expenditure (billion lempiras)	0.70	54.2 percent
Combined emissions (thousand tons)	406.07	
Combined emissions (billion lempiras)	0.16	12.7 percent
Cell phone expenditure (billion lempiras)	0.43	33.2 percent
Dividend in 2016		
Lighting expenditure (billion lempiras)	0.12	54.2 percent
Combined emissions (tons)	36.49	
Combined emissions (billion lempiras)	0.03	12.7 percent
Cell phone expenditure (billion lempiras)	0.07	33.2 percent

3. EXTENDING THE ENERGY ACCESS DIVIDEND TO INCLUDE TIERED ACCESS



3. Extending the Energy Access Dividend to include tiered access

3.1

What is the EAD from enhanced electricity access?

Analysis of the basic EAD for Honduras is illustrative of a key limitation of applying that framework to a case where progress towards universal electrification is already well advanced. The EAD for basic access in such situations is quite modest, both compared to Honduras's GDP as well as to the basic EAD for Haiti, suggesting that, perhaps, Honduras does not have much to gain by pursuing a basic electricity-focused development agenda. This binary approach to electricity access—that is, having any electricity access or not—however ignores the potentially significant effects of improving the quality of electricity access. This chapter thus considers a broader conception of the EAD, by incorporating benefits that accrue to households based not only on the presence of electricity in the household but also on improvements in the quality and reliability of that electricity access.

In an effort to take a more nuanced approach to understanding household energy access, SEforALL and ESMAP created the Multi-Tier Framework (MTF) for characterizing electricity access according to characteristics such as capacity, duration, reliability, quality, legality, and safety (Bhatia and Angelou, 2015). This framework, and subsequent data collection efforts to describe country-specific differences in access across the tiers (World Bank and ESMAP, 2018), allow for the extension of the EAD framework to include tiered access. These data make it possible to incorporate a more accurate conception of electrification status that facilitates inclusion of benefits that were previously outside the scope of the EAD.

This analysis explores an extended EAD concept for Honduras for two primary reasons. First, the availability of household-level MTF data facilitates this richer analysis; similar data are not currently available for Haiti. Second, the distribution of electricity access across tiers in Honduras is much more relevant than the binary conception of access as included in the basic EAD. In particular, while the country has high levels of basic electrification, only 45 percent of urban households and 32 percent of rural households enjoy tier 5 access, indicating that there may be very important benefits to improving the quality of electricity access in Honduras.

3.2

Calculating the Energy Access Dividend for improved connections

The expanded EAD calculation rests on the framework outlined in Section 2 but differs from it in four key ways. First, central to the calculation is the distribution of households across tiers of electricity access. That is, households with basic levels of electricity are not omitted from the calculation; rather, the EAD for these households incorporates the forgone benefits that result from the households remaining with only minimal access (i.e., tier 1) rather than reaching a higher tier of access (e.g., tier 5). In order to aid policy making about the incremental value of specific pathways to universal access, this higher tier level can be varied. For example, if it is tier 1, the EAD in the extended calculation simply corresponds to that presented in Chapter 2 and represents the forgone benefits that affect only the set of households lacking basic access. If it is tier 5, the extended EAD represents the sum of foregone benefits from the much larger group of all households lacking tier 5 access, which would require universal access to a reliable and high-capacity grid connection. Finally, if it is tier 3, the extended EAD represents the sum of forgone benefits to some intermediate number of households (between the smallest set lacking basic access and the largest set lacking tier 5 access) who lack tier 3 access, which would require universal access to a microgrid or lower quality grid connection.

Second, as data quality and availability are good for Honduras, the additional benefits that depend on higher quality access can be included and valued in the analysis. As discussed in the introduction, these additional benefits include ownership of electricity-using assets and gains from reduced power interruptions. Third, the extent of different categories of benefits accruing to households can be differentiated according by tier. For example, differences in use of specific appliances as a function of electricity quality can be included. Finally, the extended EAD leverages household data to better determine the EAD that is relevant for different (e.g., rural vs. urban) target populations. The sum of these population-specific EADs is equal to the overall, national-level EAD, but their distribution can inform more strategic and impactful targeting of energy access interventions. And while these extensions add nuance to the EAD calculation, the key inputs and structure remain consistent with those required for the EAD for basic connections: (i) the incremental benefits of electricity access provided with each increase in tier, (ii) the number of households lacking electricity access in each tier in each year, and (iii) the projected number of years it will take to achieve the highest (i.e., tier 5) access.

3.2.1
Monetizing benefits

To facilitate comparison of the various benefits in the extended EAD, all benefits are again reported in monetary terms[14]. For expenditure savings or reduced income loss, the process of monetization is straightforward and based on actual estimates of the value of these forgone benefits, subject again to caveats about the market distortions that may bias these values to some extent. Benefits accrued in non-monetary units—emissions, time savings, and asset ownership—are valued according to methods commonly utilized in the literature and summarized below.

14. Benefits not originally in monetary terms are also reported in their original units.

Valuing emissions reductions: Reductions in kerosene consumption result in decreased emissions of the same climate-affecting pollutants— carbon dioxide (CO2), black carbon (bc), methane (CH4), carbon monoxide (CO), nitrogen oxide (N2O), and organic carbon (oc)—included in the basic EAD. These emissions reductions are again converted into global warming potential and valued using the social cost of carbon (Jeuland et al., 2018).

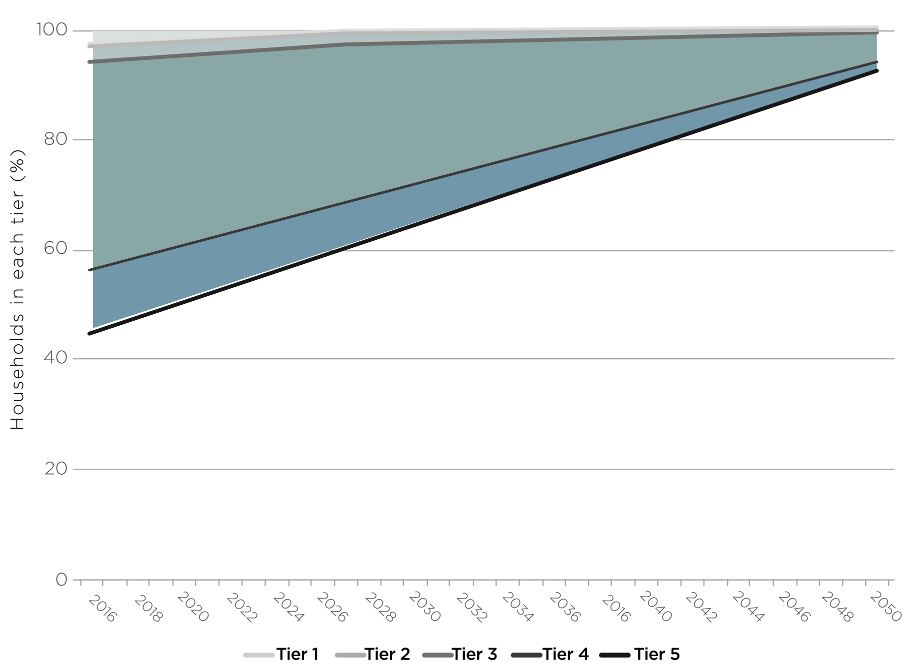
Valuing study time: The literature is inconclusive regarding the extent to which improved electricity access and quality affects the distribution of households' time allocation, so changes in study time are elicited directly from household-level survey data from Honduras. In this report, any time allocations towards studying among children that occur differentially across the tiers of access are valued using half of the unskilled minimum wage rate (Whittington and Cook, forthcoming).

Valuing the gains from asset ownership: Ownership of electricity-using assets including radios, fans, televisions, and refrigerators offer households a variety of benefits. First, these products may be welfare enhancing by providing utility though leisure (i.e., enjoyment of watching or listening to a television or radio program). Second, some appliances may increase household efficiency and/or productivity. Refrigeration allows for food storage, decreasing cooking requirements; fans provide cooling, which may increase household productivity (Burke et al., 2015; Davis and Gertler, 2015). Full valuation of these benefits requires subtracting the cost of acquiring and using the appliance in question from households' willingness to pay for it. In the absence of data on the running costs associated with use of appliances, the benefits of asset ownership are valued by estimating the consumer surplus of each asset (Boardman et al., 2017)[15].

3.2.2
The "business-as-usual" trajectory across energy access tiers

In order to calculate the extended EAD, a baseline or "business-as-usual" electrification transition must be established. Historical trends in electrification and government targets for access rates could provide the basis for developing this baseline, but detailed historical data on the distribution of access across tiers are limited to a single recent MTF survey. Given the lack of data from which to extrapolate the movements across tiers in Honduras, the analysis relies on a simple transition assumption as detailed below.

Figure 5: Electricity access baseline by tier, urban Honduras

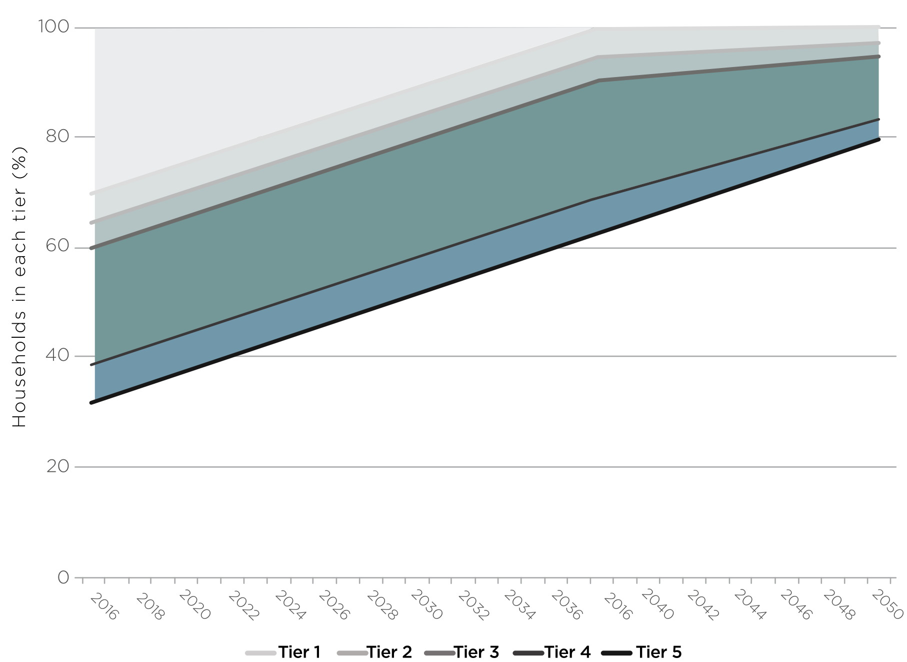


15. The calculation of consumer surplus is discussed in Appendix B.

The “business-as-usual” electricity transition pathway for Honduras is defined separately for urban (Figure 5) and rural (Figure 6) populations, given the important differences in access to connections across these two groups. Specifically, because urban electricity access is already so high, urban Honduras has seen a low annual rate of electrification expansion at just 0.2 percent per year. Meanwhile, the historical increase in rural electrification has been 1.4 percent per year. The starting point for setting the extended EAD baseline is to apply these historic rates for urban and rural areas to estimate the “business-as-usual” transition from tier 0 to tier 1. The historical electrification rate for rural areas (1.4 percent) is then assumed to represent the transition into tier 5 access, for both rural and urban populations. Finally, the transitions from lower tiers into tiers 2, 3, and 4, respectively, are calculated to maintain a stable proportion of households across these tiers over time.

The extended EAD then applies to households occupying the space between the lines reflecting household connections at each energy tier and universal tier 5 access (i.e., the area colored by the different shades of green in Figure 5 and Figure 6). When calculating the EAD for alternative access targets, such as universal access to at least tier 3 microgrids, the benefits of the higher tiers (e.g., tier 4 and tier 5) are omitted. Thus, the basic EAD calculation presented in Section 2 pertains only to households occupying the area above the tier 1 line (i.e., the lightest green area in Figure 5 and Figure 6) and includes only the benefits experienced in moving from tier 0 to tier 1.

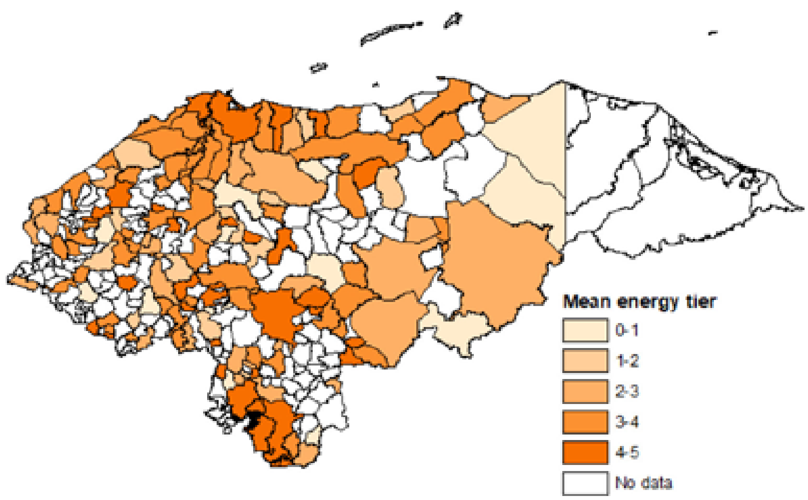
Figure 6: Electricity access baseline by tier, rural Honduras



In this report, the baseline is estimated for the time horizon of 2016 to 2040, and the EAD is calculated over this time period. There are two primary reasons the time horizon is constrained to 2050. First, as the EAD is calculated based on population and energy access projections, these data become less certain as the time horizon increases. Second, as all future monetary benefits included in the EAD calculation are discounted at a rate of 12 percent, benefits far into the future add little to the EAD calculation, although application of the lower 5 percent discount rate places much more emphasis on these future benefits.

Finally, it is worth discussing the spatial distribution of household access to different energy tiers at the start of the analysis (in 2016), since this provides insights on where the greatest EAD lies. Figure 7 provides a map of the distribution of average energy access tier for each municipality of Honduras for which data are available (municipalities in white were not included in the MTF survey). Municipalities that are shaded in darker orange – which include some of the largest cities in Honduras including Tegucigalpa, San Pedro Sula, and La Ceiba – have, on average, higher tier connections[16].

Figure 7: Mean energy tiers by municipality, Honduras. Data to generate this map come from the MTF survey for Honduras (World Bank and ESMAP, 2018). The municipalities marked with "no data" were not part of the MTF sample, so this paper does not report mean energy tier in these areas.



16. A similar map depicting the most common energy tier by municipality in Honduras is available in Appendix B.

3.2.3
Scenarios to evaluate

While the simple EAD calculation considers only the electricity transition to universal basic access, three scenarios are evaluated and compared as part of the extended EAD framework. The scenarios evaluated are designed to align with policy relevant options in Honduras; accordingly, if the extended EAD framework was applied to another country, the relevant scenarios may differ. The three scenarios, summarized by Table 5, include:

1. Universal tier 5 electrification (high quality grid expansion scenario)

2. Universal tier 3 electrification (microgrid expansion scenario)

3. A hybrid of tier 3 and tier 5 electrification, where tier 3 access would be focused on rural areas with less than tier 3 access, and tier 5 access would be focused on urban areas lacking tier 5 access.

Scenario 1, universal tier 5 electrification, represents the upper bound of the EAD. It considers the benefits that Honduras would enjoy if universal tier 5 electrification was achieved immediately rather than according to the baseline established in Section 3.3.2. This scenario provides an upper bound on all scenarios of EAD calculations, as the full suite of identified and parameterized benefits are applied to all households for each year they go without tier 5 electricity. Tier 5 access is feasible only through formal, grid connections, as tier 5 electricity access is high quality, reliable, formal, and safe. Thus, this scenario is associated with a policy approach that prioritizes extension of the grid to reach currently unconnected areas and households.

Scenario 2, universal tier 3 electrification, represents a mid-range scenario that affords all households in Honduras access to at least eight hours of electricity per day at a high enough quality to support basic household appliances. It is calculated over the benefits that Honduras would enjoy if universal tier 3 electrification was achieved immediate rather than according to the baseline established in Section 3.3.2. This scenario allows for non-grid access, primarily in terms of microgrid and renewable options, rather than relying on grid expansion. In Honduras, most of the unconnected households are in rural areas, which are often remote and challenging to connect to the grid. Accordingly, scenario 2 offers a relevant and practical solution to rural electrification through off-grid options.

Scenario 3, hybrid tier 3 or 5 electrification, represents a scenario that provides mid-range electricity access to all households but also improves the quality and reliability of these connections over time. In this scenario, the benefits of the immediate transitions of rural households to tier 3 and urban households to tier 5 are compared to the baseline established in Section 3.3.2. A combination of electrification pathways is required in this scenario; grid-based connections are necessary to facilitate expanding tier 5 access and tier 3 access can be achieved through either grid or off-grid options. Thus, scenario 3 offers a realistic scenario in which Honduras expands the current grid but does not necessarily reach universal grid-connections in the short term as unconnected households can still achieve tier 3 access through off-grid solutions.

Table 5: EAD scenarios, Honduras

Scenario	Process	Time Frame	Policy Relation
Universal tier 5 electrification	All households transition to tier 5 immediately	2016-2050	Universal grid coverage
Universal tier 3 electrification	All households transition to tier 3 immediately; households in tiers 3, 4, and 5 at baseline remain in original tiers	2016-2050	Microgrid and renewable expansion
Hybrid tier 3 or 5 electrification	All households in rural areas below tier 3 transition to tier 3 immediately; all households in urban areas below tier 5 transition to tier 5 immediately	2016-2050	Combination of grid, microgrid, and renewable expansion

3.2.4
Assumptions and methodological limitations

While the extended EAD framework addresses some of the limitations highlighted in the basic EAD calculations (SEforALL and Power for All, 2017), it also imposes assumptions of its own that deserve discussion. The first major limitation of the extended EAD is that not all benefits associated with electrification access can be included. Specific categories of benefits that are not included are the health benefits of electrification, and the expanded use of electricity in small scale production (e.g., from small enterprises) that is not covered in the household-level MTF surveys. Second, as with the basic EAD, the costs of electricity provision and use are not included for comparison with the forgone EAD benefits. Clearly this omission challenges the extent to which the EAD calculations can inform policy. These limitations are further discussed in Section 4.2.

Assumptions made in parameterizing the extended EAD model are discussed in detail in the technical appendix, but three specific assumptions are identified here. First, much of the parameterization of the extended EAD model comes from regression analysis conducted on cross-sectional, household survey data from Honduras (World Bank and ESMAP, 2018). These estimations yield correlations that control for basic demographic and economic household characteristics, but identification of causal relationships between tiered electricity access and these benefits using such data is challenging[17.] These estimates, therefore, should be treated with caution. Second, assumptions on the social cost of carbon, valuation of children's time, and calculation of consumer surplus (see Section 3.3.1) are made in the process of converting emissions, time change, and asset ownership benefits to monetary values. Third, as discussed above, the "business-as-usual" electrification trajectory across tiers for Honduras rests on fairly limited data.

17. Appendix B provides additional detail on methods used to generate model parameters.

3.3

Extending the Energy Access Dividend in Honduras

3.3.1
Indicators and data for extended EAD, Honduras

This section summarizes the indicators and data sources used to calculate the extended EAD for Honduras[18]. As the indicators and data for calculating energy access, population, and household size; lighting expenditures; emissions; and cell phone charging are described in Section 2, these descriptions are not repeated here. For the extended EAD, relevant parameters are defined in the same way. For study time, the calculation differs somewhat in the extended EAD framework, given that the relationship between study time and electricity access varies across tiers. Descriptions for radio, fan, television, and refrigerator ownership as well as electricity reliability follow below.

Study time: Although examination of study time trends across the representative sample of households in Honduras does not reveal significant associations between study time and electricity access, analyses between tiers and for rural and urban populations suggest a potentially more nuanced relationship. Specifically, there is evidence of more time spent studying among children in households with tier 3 electricity access compared to those in households with tier 2 access. Among urban populations, there is no evidence of increased study time among girls; however, tier 3 households report that boys spend more time studying compared to tier 2 households, controlling for household demographic and economic characteristics. The estimate corresponds to an increase of about 7 hours per month, or 84 hours per year. For rural households, on the other hand, study time changes are higher in tier 3 for girls, by about 2 hours per month, compared to tier 2 households.

Radio ownership: Radios are among the first electricity-using assets electrified households purchase as the energy required to run a radio is minimal. Households in Honduras are more likely to have radios in tier 1 compared to tier 0, but no other increases in ownership occur at higher tiers. In urban settings, tier 1 households, on average, own 0.4 more radios compared to tier 0 households, holding household demographic and economic characteristics constant; for rural households, the difference is 0.1 radios. Yearly consumer surplus associated with radio ownership is estimated at 108 lempiras ($4.5 USD) per household per year.

Fan ownership: The data suggest that Honduran household begin to acquire fans once they achieve tier 2 access. In urban settings, tier 2 households, on average, own about 0.7 more fans than tier 1 households, holding household demographic and economic characteristics constant; for rural households the difference is about 0.3 fans. Yearly consumer surplus associated with fan ownership is estimated at 37 lempiras ($1.5 USD) per household per year.

Television ownership: The data from Honduras suggest that tier 2 and tier 3 electricity access is compatible with television ownership. In urban settings, tier 3 households, on average, own about 0.3 more televisions compared to tier 2 households, holding household demographic and economic characteristics constant. In rural settings, the significant difference appears between tier 1 and tier 2 households, with tier 2 households, on average, owning 0.6 more televisions. Yearly consumer surplus associated with television ownership is estimated at 411 lempiras ($17.1 USD) per household per year.

18. All parameters for the EAD calculated for Honduras are presented in Appendix BiError! No se encuentra el origen de la referencia.

Refrigerator ownership: The data suggest that Honduran households begin purchasing refrigerators once they have access to tier 2 or tier 3 electricity. In urban settings, tier 2 households, on average, own 0.5 more refrigerators compared to tier 1 households, and tier 3 households own about 0.3 more refrigerators than tier 2 households, holding household demographic and economic characteristics constant. In rural settings the difference between tier 1 and tier 2 ownership is 0.12 refrigerators and between tier 2 and tier 3 households is 0.4 refrigerators. Yearly consumer surplus associated with refrigerator ownership is estimated at 560 lempiras ($23.3 USD) per household per year.

Electricity reliability: The household-level survey data from Honduras elicits monthly income losses that households experience as a result of poor electricity reliability. These losses are quite high for mid-tier households (because low-tier households do not have the energy capacity to use electricity for productivity) and appear to decrease among high-tier households. In urban settings, this reduced income loss, estimated at 530 lempiras per month ($22 USD) accrues to households achieving tier 5 access. Among rural households, there is little evidence of significant reductions in income loss associated with increased electricity reliability, in part because few households report electricity use for income generating activities. There is evidence, however, that as households move up the energy tiers, they are less likely to report income loss associated with electricity reliability. That is, households in tiers 4 and 5 are less likely to report electricity-related income losses than households in tier 3. Thus, to capture some reliability benefits associated with higher tier access in rural areas, these differences in reported income loss are multiplied by the average loss reported, yielding estimates of reduced income loss of 25 lempiras per month ($1.04 USD) in tier 4 and 31.2 lempiras per month ($1.30 USD) in tier 5.

3.3.2 Estimating the extended Energy Access Dividend, Honduras

The extended EAD for each electrification transition pathway for Honduras is calculated here. These dividends are calculated across the time period spanning 2016-2050. During this period, Honduras does achieve universal basic electrification; however, it does not reach universal tier 5 electrification according to the assumed urban and rural baselines (see Figure 5 and Figure 6) used for comparison. The present value of the EAD, calculated using a discount rate of 12 percent, is presented for each electrification transition scenario.

The present value of the EAD calculated for scenario one – universal access to tier 5 electricity – is 6.4 billion lempiras ($266.5 million USD), as shown by Figure 8 (using a 5 percent discount rate, this estimate rises to 10.3 billion lempiras, and the undiscounted total is 16.9 billion lempiras). The EAD calculated for the first year (2016) is 0.9 billion lempiras ($36.6 million USD). As the cumulative EAD accrued across the entire time horizon is about 2.5 times greater than the EAD calculated in Section 2 for basic electricity access, it is clear that considering additional characteristics of household electrification beyond basic access—particularly for a country that has high access levels at baseline—is an essential component of contextualizing the benefits forgone through delayed, high-quality electrification.

Figure 8: EAD for universal tier 5 electrification (grid), Honduras

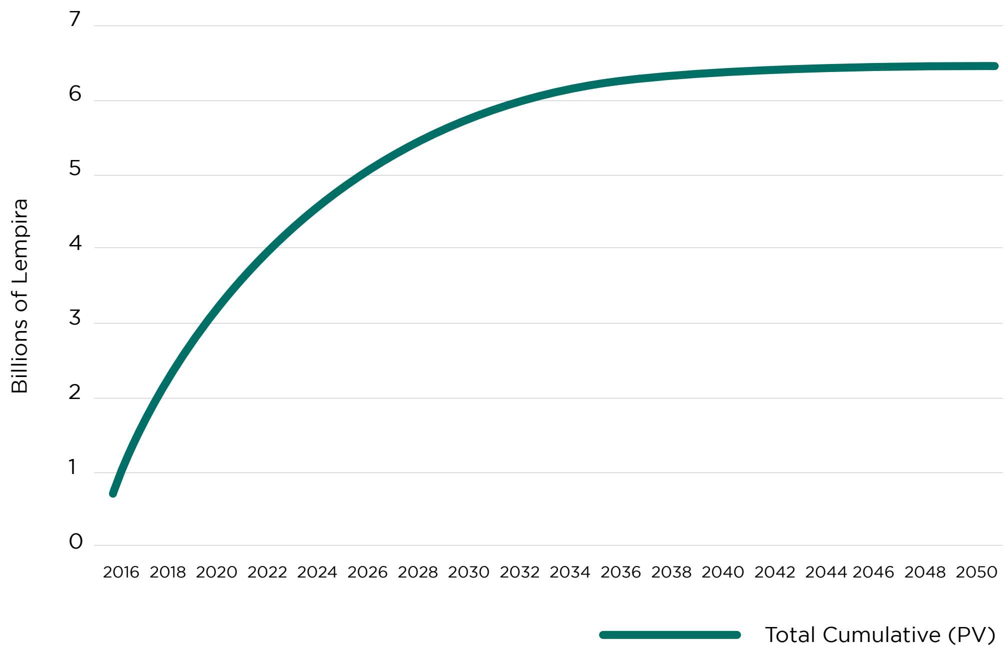
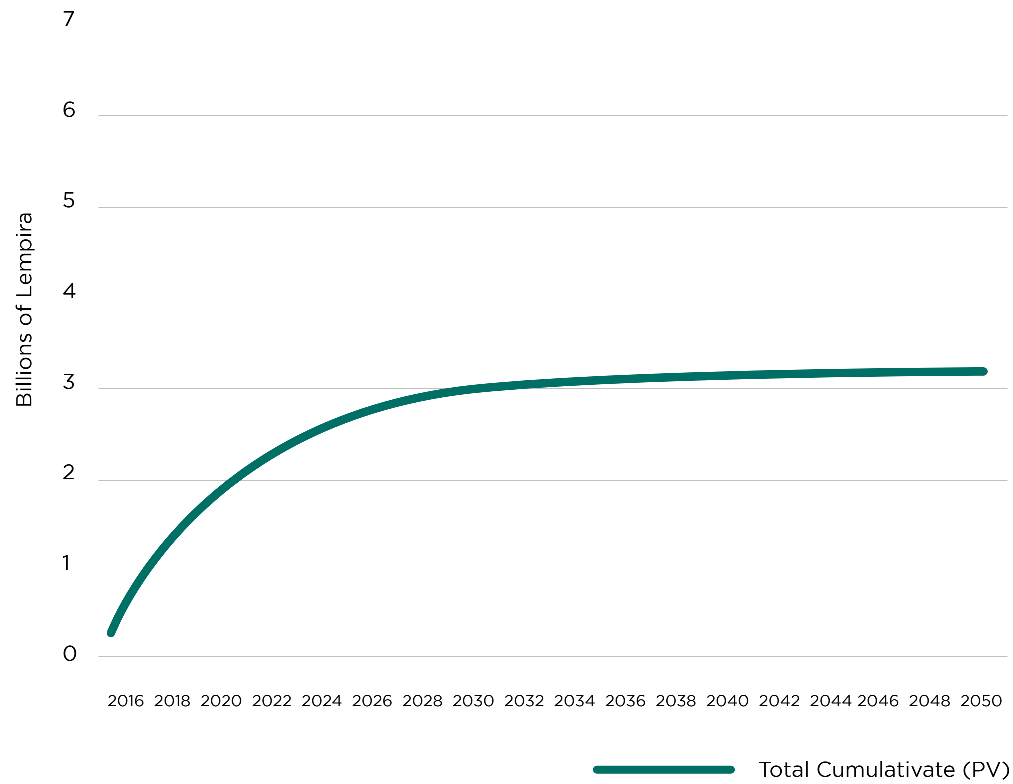


Table 6 reports the distribution of benefits included in the EAD calculation for scenario one. Nearly 50 percent of the EAD is generated by improved electricity reliability, suggesting substantial productive benefits associated with universal tier 5 access; asset ownership generates another 25 percent of the EAD; changes in study time contribute about 1.5 percent; and the remainder consists of lighting and cell phone charging expenditure and emissions reductions.

The EAD calculated for scenario two is 3.2 billion lempiras ($131.7 million USD), as shown by Figure 9 (using a 5 percent discount rate, this estimate rises to 4.8 billion lempiras, and the undiscounted total is 7.0 billion lempiras). The EAD calculated for the first year (2016) is 0.5 billion lempiras ($20.7 million USD).

Table 6 also reports the distribution of benefits included in the EAD calculation for scenario two. Under this scenario, there are no dividends generated by improved electricity reliability; asset ownership generates nearly 50 percent of the EAD; changes in study time contribute 2.8 percent; lighting and cell phone charging contribute about 21 percent, each; and the remainder of the EAD results from emissions reductions.

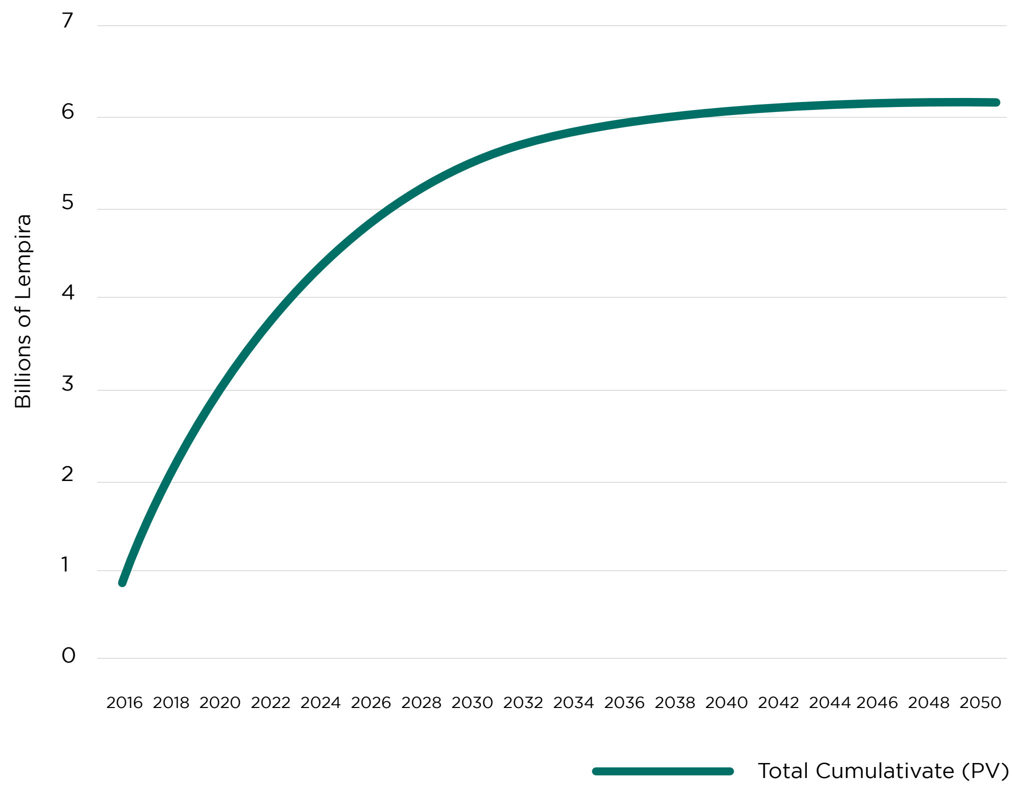
Figure 9: EAD for universal tier 3 electrification (off-grid), Honduras



The EAD calculated for scenario three is 6.1 billion lempiras ($255.4 million USD), as shown by Figure 10 (using a 5 percent discount rate, this estimate rises to 9.9 billion lempiras, and the undiscounted total is 16.1 billion lempiras). The EAD calculated for the first year (2016) is 0.8 billion lempiras ($35.2 million USD).

Table 6 also reports the distribution of benefits included in the EAD calculation for scenario three. About 47 percent of the EAD is generated by improved electricity reliability; asset ownership generates nearly 26 percent of the EAD; changes in study time contribute 1.6 percent; and the remainder consists of lighting and cell phone charging expenditure and emissions reductions.

Figure 10: EAD for hybrid tier 3 or 5 electrification, Honduras



Comparison across EAD scenarios demonstrates that the benefits of electricity access extend far beyond a household's access to basic, tier 1 electricity. A binary treatment of electricity that considers basic access to electricity only thus omits substantial forgone benefits in Honduras. This is an intuitive but important result that is consistent with the energy access literature; it is obvious that access to four hours of electricity a day with the capacity to power a single light bulb presents vastly different benefits than access to twenty-three hours of electricity a day with the capacity to power large appliances. These extended EAD calculations provide an initial framework for considering and valuing the differences associated with the quality of energy access. Thus, even countries like Honduras that have made impressive strides towards universal electrification may be missing important benefits if additional resources are not allocated to improving the quality and reliability of modern energy access.

Table 6: Extended EAD by benefit type, Honduras

	Universal Tier 5	Universal Tier 3	Mixed Tiers 3 and 5
Cumulative Dividend			
Lighting expenditure (million lempiras)	677.5	677.5	677.5
Combined emissions (thousandtons)	39.3	39.3	39.3
Combined emissions (million lempiras)	171.8	171.8	171.8
Cell phone expenditure (million lempiras)	693.2	693.2	693.2
Radio (number of radios)	501807.8	501807.8	501807.8
Radio (million lempiras)	82.2	27.8	82.2
Fan (number of fans)	534104.3	534104.3	534104.3
Fan (million lempiras)	25.0	25.0	25.0
TV (number of TVs)	1237078.8	1237078.8	1237078.8
TV (million lempiras)	608.0	608.0	608.0
Refrigerator (number of refrigerators)	1080356.2	1080356.2	1080356.2
Refrigerator (million lempiras)	855.9	855.9	855.9
Girl's study time (hours)	2712844.9	2712844.9	2712844.9
Girl's study time (millions of lempiras)	62.0	62.0	62.0
Boy's study time (hours)	4076223.9	4076223.9	4076223.9
Boy's study time (millions of lempiras)	39.4	39.4	39.4
Income not lost (million lempiras)	3181.3	0.0	2913.9
Yearly Dividend			
Lighting expenditure (million lempiras)	113.0	113.0	113.0
Combined emissions (tons)	3213.3	3213.3	3213.3
Combined emissions (million lempiras)	28.6	28.6	28.6
Cell phone expenditure (million lempiras)	112.4	112.4	112.4
Radio (number of radios)	47537.9	47537.9	47537.9
Radio (million lempiras)	12.4	4.8	12.4
Fan (number of fans)	17286.3	17286.3	17286.3
Fan (million lempiras)	3.9	3.9	3.9
TV (number of TVs)	39851.1	39851.1	39851.1
TV (million lempiras)	91.8	91.8	91.8
Refrigerator (number of refrigerators)	35260.6	35260.6	35260.6
Refrigerator (million lempiras)	127.5	127.5	127.5
Girl's study time (hours)	83949.5	83949.5	83949.5
Girl's study time (millions of lempiras)	9.4	9.4	9.4
Boy's study time (hours)	148951.8	148951.8	148951.8
Boy's study time (millions of lempiras)	5.5	5.5	5.5
Income not lost (million lempiras)	374.3	0.0	339.8

4. DISCUSSION AND RECOMMENDATIONS

4. Discussion and Recommendations

4.1

Energy Access Dividend Findings

Expanding the EAD calculations to incorporate both additional categories of benefits of electrification as well as the nuance of benefits that vary across energy tier provides additional insights into the dividends that could be gained by increasing the speed of electrification transitions. By comparing the basic EAD presented for Honduras with the expanded calculations, it becomes apparent that benefits beyond basic electrification—including increased asset ownership and improved reliability at higher energy tiers—provide benefits to households that are difficult to capture when all electrification, or access to electricity, is treated equally. Comparing the present values of the basic EAD for Honduras to the extended calculations demonstrate this point: The basic access EAD is 1.4 billion lempiras, whereas the extended access EAD is between 3.2 and 6.4 billion lempiras, depending on the electrification scenario considered[19]. Furthermore, within each scenario calculated, there are gaps and limitations to the valuation exercise, suggesting that additional benefits, particularly at higher energy tiers, which currently do not enter the EAD could further increase the dividend calculation.

A second key point that stems from the EAD comparison across the Haiti and Honduras case studies is the value of household-level survey data on energy access and utilization in estimating the EAD. In the absence of survey data, the Haitian model is parameterized first by using country-level statistics and second by adapting data from outside of Haiti (i.e., the Honduras MTF data) to the Haitian context. As there exists variation in some of these figures, additional uncertainty enters into the EAD calculation for Haiti through the model parameterization.

4.1.1
Energy Access Dividend at the household level

While the aggregated EAD calculations provide insight into the dividends associated with electrification transitions at the national level, so too do these benefits have implications at the household level. Table 7 shows the household-level EAD for each of the electrification scenarios: basic access in Haiti and Honduras, and the three extended tier-based scenarios

19. These figures for the dividends calculated with a discount rate of 5 percent are 1.7 billion lempiras for basic access and between 4.5 and 9.6 billion lempiras for expanded access. Similarly, the undiscounted figures are 2.2 billion lempiras for basic access and between 6.6 and 15.7 billion lempiras for expanded access.

for Honduras. In the basic EAD calculations, which do not account for tier-based variation in access, the yearly household EAD is about 717 lempiras ($30 USD) in Honduras and 2126 gourdes ($30 USD) for Haiti.

Within the extended EAD model for Honduras, which does account for variation across energy tier, there surfaces the expected pattern that households in lower tiers have higher EAD calculations than those already enjoying higher electricity quality and reliability. Furthermore, for low energy tiers, rural households have higher dividends, while for higher energy tiers, urban households have higher dividends. These results are based on the findings within the household-level survey data from Honduras that show reliability-based benefits for urban, but not rural, households. Given the inability of the EAD to capture all benefits associated with increased electricity access at each tier, these tier-based calculations are intended to provide a first estimate of the distribution of the EAD across tiers, rather than suggest where policy would be best targeted. This is especially important as the ability to capture tier-based benefits is not consistent across the tiers. For example, there may be benefits associated with productive use for households in tiers 4 and 5, but data availability limits the ability to incorporate these benefits into the EAD calculation, which artificially decreases the EAD attributed to higher energy tiers.

Table 7: Household EAD

	Honduras*				Haiti**
2016 EAD per household	**Basic Access**	**Universal Tier 5**	**Universal Tier 3**	**Mixed Tiers 3 and 5**	**Basic Access**
Tier 0		475.2/333.7	350.1/320.6	475.2/320.6	
Tier 1		299.0/171.5	173.9/158.5	299.0/158.5	
Tier 2		206.1/60.0	81.1/46.9	206.1/46.9	
Tier 3		125.1/13.1	0/0	125.1/0	
Tier 4		125.1/7.3	0/0	125.1/0	
Tier 5		0/0	0/0	0	
Un -tiered	717				2126

*Results for Honduras presented as urban/rural (in lempiras). **Results for Haiti presented in gourdes.

4.1.2
Energy Access Dividend in relation to Sustainable Development Goals

Sustainable Development Goal (SDG) number 7 identifies the benefits of energy access to combating poverty and improved economic development and sets a target for universal access to affordable and reliable energy by 2030. The “business-as-usual” trajectories for electrification in Haiti and Honduras reflect countries which have made differential progress towards achieving this goal, at least with regard to universal electrification. Honduras has made significant progress towards universal electrification with projections of current rural and urban electrification rates suggesting that universal access will be achieved in urban areas by 2028 and in rural areas by 2038. While the rural projection falls short of SDG 7’s 2030 target, non-grid electrification offers one pathway through which rural electrification could increase more rapidly, as modeled in the tier-based EAD calculations for scenarios 2 (universal tier 3) and 3 (mixed tiers 3 and 5). Haiti’s electrification lags behind the 2030 target, with projections of current electrification rates delaying universal electrification until 2150. Haiti, therefore, could benefit from an increased rate of electrification, which could be based on non-grid options, that would allow the country to capture the dividends associated with basic electrification.

While SDG 7 presents the clearest connection to the EAD concept, the relationship between energy and development expands beyond basic access, as demonstrated by the benefits included in the EAD calculation. SDG 4 focuses on quality education. While the relationships between electricity access and educational measures remain unsettled, the expanded EAD for Honduras suggests there are educational gains to electrification, presenting a complementarity between these sustainable development goals. Similarly, SDGs 10 (reduced inequalities) and 13 (climate action) also relate directly to the EAD concept, particularly in its extended form. The tiered approach to calculating and presenting the EAD explicitly identifies inequalities in access, as the calculation is based on six categories of energy tiers rather than one metric of electricity access. Additionally, both the basic and extended EAD seek to demonstrate the climate-related benefits associated with reduced kerosene consumption to highlight complementarities between increased access to modern energy and efforts to reduce emissions.

4.2
Recommendations for future research

The extended EAD methods and calculations presented in this report expand on the framework developed by the "Why Wait? Seizing the Energy Access Dividend" report (SEforALL and Power for All, 2017), yet still face some of the same methodological and data limitations, on which future work could focus. Two important categories of potential future extensions to this framework are outlined below.

4.2.1
Benefits outside the scope of this report

As with the expansion of the basic EAD framework presented in this report, future work calculating the EAD should incorporate additional categories of benefits including health benefits, productive benefits, and time use changes, which have been qualitatively identified in both the "Why Wait? Seizing the Energy Access Dividend" report (SEforALL and Power for All, 2017) and this report yet not quantitatively valued for inclusion in the EAD. There are several potential mechanisms through which electricity access could provide health benefits. First, refrigeration improves the quality of food storage, decreasing contamination. Similarly, for both households and healthcare facilities, refrigeration allows for the use and distribution of temperature-sensitive medications. In addition, health benefits associated with reduced kerosene emissions are a relevant benefit to the EAD calculation.

Second, as households achieve higher energy tiers, they have access to electricity to that is higher capacity and quality and is more reliable. Households and small industries, once electrified at these higher tiers, use electricity for production, which may allow them to operate more efficiently or grow. Similarly, electrification in agriculture (e.g., electric water pumps) can yield productive benefits in agrarian settings.

Finally, while the literature is limited regarding causal relationships between electricity access and time-use changes, there are potential time-related benefits to electrification that could be incorporated into the EAD along with study time. These benefits include time use for leisure, domestic work, and income-generating work. There are several mechanisms through which these time use changes could occur. Electricity at night can expand the number of working hours available to the household, allowing for the reallocation of time to various household activities. For example, if domestic work can be completed in the evening, household members may spend more time on income-generating work outside the home. It is not clear, however, how these time-use substitutions are made within the household, disallowing for their valuation in this report. Disentangling the relationship between household time use and tiered electricity access would be a valuable extension to the EAD framework.

4.2.2 Costs of electricity provision

In addition to expanding the types of benefits included in the EAD, a valuable and insightful extension of the EAD would include not only the benefits of electrification but also their costs. Without costs, the policy recommendations of the EAD calculation are limited as the costs associated with various electrification scenarios are unobserved by the analysis. There are two primary categories of costs relevant to the EAD concept: (i) household costs and (ii) infrastructure and provision costs.

In the current EAD framework, the benefits calculated are gross benefits, which do not take into account household expenditures required to obtain these benefits. For example, while households do enjoy the benefits of reduced expenditures on kerosene for lighting, they must pay for electric lighting as a substitute to enjoy these benefits. Similarly, while households forgo expensive cell phone charging outside of the home, they incur costs associated with the private use of electricity, and there are emissions produced from electricity generation that decrease the overall emissions benefits of shifting to a cleaner fuel source. Furthermore, there may be fixed connection or technology costs for electricity access, which are not factored into the EAD calculation. With data on household electricity expenditures and information regarding a country's electricity generation by source, some of these household costs could be incorporated into a future EAD framework.

Similarly, there are costs associated with electricity access in the form of infrastructure expansion both for increased electricity generation as well as transmission. A complete cost benefit analysis of electrification would consider how these costs compare to the benefits of electrification and generate policy recommendations based on both benefits and costs. While comprehensive data on costs related to infrastructure expansion is not readily available, a 2010 ESMAP report for Honduras identifies investment costs of new electricity access by technology, suggesting that new grid connections cost between $400-1,000 USD; new connections via diesel plans between $950-3,800 USD; new connections via microhydro between $2,700-3,300 USD; and new connections via solar home systems between $400-750 USD, depending on capacity. These findings suggest substantial variation in the costs associated with different electrification technologies and that the viability of a connection offers differs across space—i.e., in remote rural areas solar home systems may be the most economical option; however, the capacity and reliability of these systems is insufficient to facilitate tier 5 access in these areas. These capital costs of new connections demonstrate that the fixed costs of electricity access should not be overlooked in a comprehensive analysis of electricity transitions.

4.3 Recommendations for policy makers

National electrification decisions and planning are important and far-reaching. While governments in many cases have tools and methods available to understand the cost of electrification options, there is a lack of tools available for understanding how much those different options provide in terms of benefits for different populations over different timeframes. Too often this benefits side of the cost-benefit analysis is filled by anecdotes. They are very real anecdotes such as children studying into the evening, access to vaccines in remote locations, and people opening new businesses. But under the pressure of limited budgets and competing priorities, anecdotes are necessary but not sufficient.

The EAD estimates for Haiti and Honduras included here—and for other countries in the future using this methodology—can help to quantify the impacts and trade-offs of different electrical system investments. We can not only understand the aggregate level of benefits that electrification can unlock, but we can see through what pathways and platforms they could be achieved, which populations benefit, and how the pace of these investments influence the level of benefits achieved. The pain of potentially expensive electrification investments can be tempered with the positive reality of what those investments could reasonably achieve, which can be invaluable in mobilizing the political will and resources needed to shift to an accelerated energy access pathway.

The EAD framework provides a structured approach to weigh the relative benefits of providing accelerated access to rural communities using distributed renewables, compared to service delivered through the grid over a longer timeframe. Experience shows that reaching universal access for the last 10-15 percent of the unelectrified population is the slowest and most costly. For example, it took countries such as China and Thailand 20 years to improve electrification rates from 30-40 percent to 85-90 percent but another two decades to reach universal access (IEA, 2017). The emergence of decentralized renewable systems have opened alternative lower-cost pathways for connecting these populations in more timely ways, which the EAD help to clarify. Similarly, the EAD can provide guidance on the relative gains of extending basic access to more people versus enhancing the access of those already served. It can and should be used in combination with energy demand forecasts, electrification scenario planning, and other key information about the local context, to prioritize pathways that provide greater dividends.

In applying the EAD for planning purposes, policy makers must consider the timing for when universal access should be achieved, population growth, regional development issues and priorities, and minimum tiers of access to be achieved within different regions. Planners should keep in mind that households in more rural and lower-income groups tend consume smaller quantities of electricity (equivalent to consumption at Tiers 1 or 2, regardless of on-grid or off-grid access), at least initially (Girardeau et al., 2018). As the Honduras case highlights, MTF data can be a powerful tool for understanding benefits that accrue as households climb the tiers of access. MTF data is now available for Ethiopia, Rwanda, Cambodia, and Honduras and should be available for many more countries in the coming months and years.

The EAD can be useful in other policy areas where a clear understanding of the benefits of electrification is required. For example, import tariffs on solar equipment is a contentious issue in many access-challenged countries. With low- and middle-income countries frequently producing little of the renewable energy equipment value chain domestically, these imports can appear attractive targets for reasons of government revenue generation or domestic manufacturing support. The EAD can be a useful tool for quantifying what those tariffs mean for reduced distributed energy system sales and the foregone benefits associated with them.

Since energy access is so fundamentally linked with other sectors and development goals, the EAD can be incorporated into planning in those sectors as well. For example, as off-grid solar solutions providing basic access bring reduced climate emissions, the potential for scaling those solutions could be integrated into a country's climate change strategy under the Paris agreement, where access-related commitments are eligible for inclusion under a country's nationally-determined contributions and the associated financing mechanisms. Energy access hold similar synergies with SDGs related to quality education, reducing inequalities, and health.

The aggregate EAD figures in this report should be used as a conservative lower-bound estimate of electrification benefits. There remain many categories of benefits that for reasons of data availability remain unquantified here. As researchers drill down further in understanding additional benefit categories related to energy access—like how households use their financial savings, health improvements, time use changes outside of increased study time, increased commercial and industrial productivity, and broader community effects (see Section 4.2)—these additional benefits should be incorporated into relevant planning.

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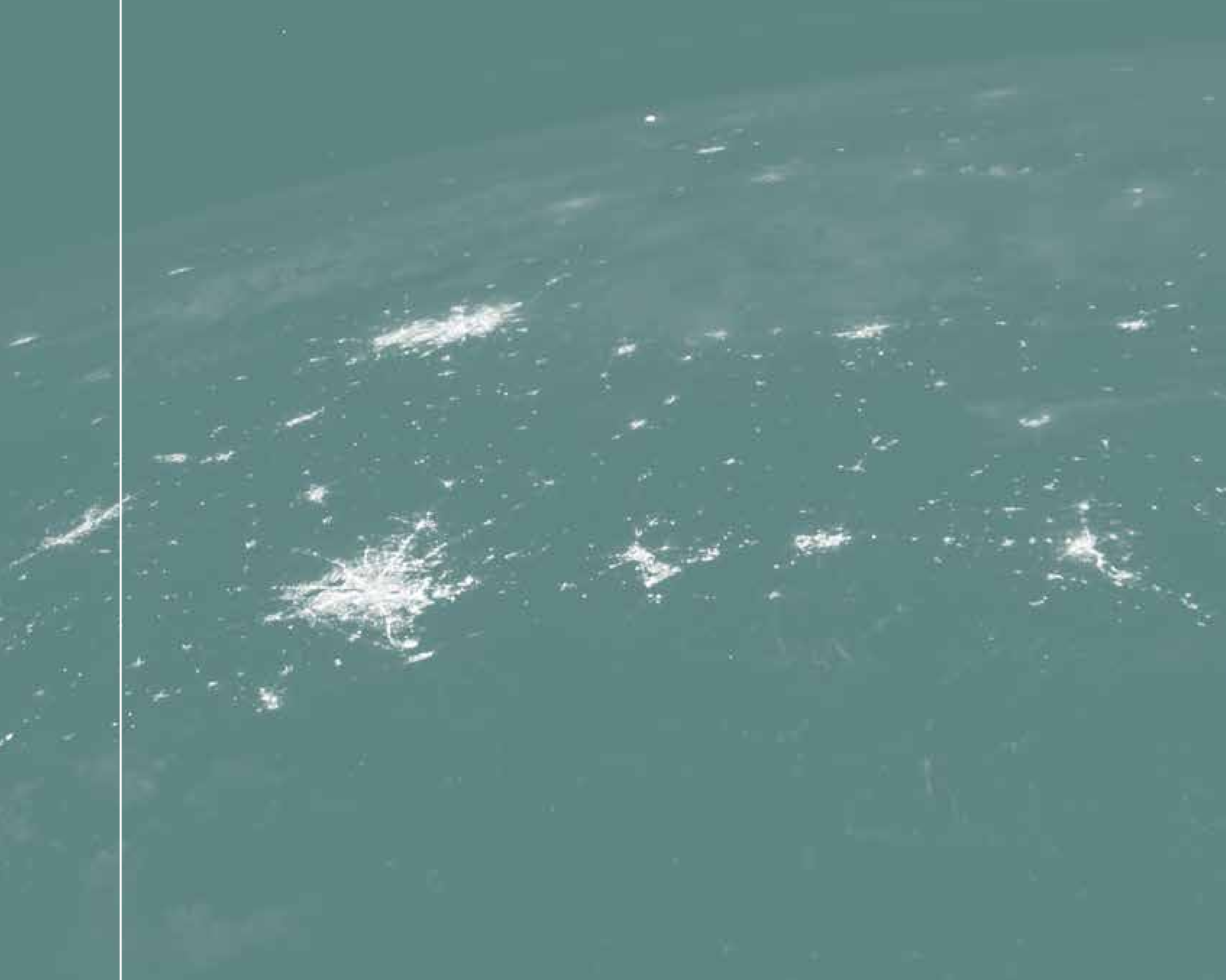

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TECHNICAL APPENDIX

Technical appendix

A. Model equations and assumptions

The Energy Access Dividend (EAD) is calculated according to Equation (1) as the sum across tiers (t from tier 0 to $t = T_s$ where T_s is the highest attained tier whose benefits are calculated in the EAD—i.e., if the EAD is calculated for basic electrification, T_s=1) and across years (y) of the benefits of electricity access at each tier $(B_{y,t_0,t_1=T_S})$ multiplied by the fraction of households who have not yet achieved that tier in a given year $(f_{y,t_0,t_1=T_S})$ multiplied by the total number of households (H_y).

$$EAD = \sum_{t=0}^{T_S} \sum_{y=1}^{Y} (1+\delta)^{-y} (B_{y,t_0,t_1=T_S}) * f_{y,t_0,t_1=T_S} * H_y \quad (1)$$

Benefits are calculated according to Equation (2) as the sum of benefits accrued from reduced lighting expenditures (B^{L}_{y,t_0,t_1}), reduced CO_2 emissions $(B^{CO_2}_{y,t_0,t_1})$, reduced black carbon emissions (B^{BC}_{y,t_0,t_1}), reduced phone charging expenditures (B^{PC}_{y,t_0,t_1}), changes in girls' study time (B^{GS}_{y,t_0,t_1}), changes in boys' study time (B^{BS}_{y,t_0,t_1}) changes in asset ownership , (B^{R}_{y,t_0,t_1}) and improvements in electricity reliabiity (B^{R}_{y,t_0,t_1}). Note that if the EAD scenario calculated does not incorporate certain benefits (i.e., asset ownership is not included in the simple EAD calculation), these are removed from Equation (2).

$$B_{y,t_0,t_1} = B^{L}_{y,t_0,t_1} + B^{CO_2}_{y,t_0,t_1} + B^{BC}_{y,t_0,t_1} + B^{PC}_{y,t_0,t_1} + B^{GS}_{y,t_0,t_1} + B^{BS}_{y,t_0,t_1} + B^{A}_{y,t_0,t_1} + B^{R}_{y,t_0,t_1} \quad (2)$$

Lighting benefits are calculated according to Equation (3) as the reduced expenditures on kerosene for lighting (E^{K}_{y,t_0,t_1}).

$$B^{L}_{y,t_0,t_1} = E^{K}_{y,t_0,t_1} \quad (3)$$

CO_2 emissions benefits are calculated according to Equation (4) as the product of the reduced consumption of kerosene $(Q^{K}_{y\ t_0\ t_1})$, the carbon emissions avoided per reduced unit of kerosene consumption $(Em^{K}_{CO_2})$, and the social cost of carbon (B^{CO_2}).

$$B^{CO_2}_{y,t_0,t_1} = (Q^{K}_{y,t_0,t_1} \cdot Em^{K}_{CO_2}) \cdot B^{CO_2} \quad (4)$$

Black carbon emissions benefits are calculated according to Equation (5) as the product of the reduced consumption of kerosene (Q^K_{y,t_0,t_1}), the carbon equivalent of black carbon emissions avoided per reduced unit of kerosene consumption (Em^K_{BC}), and the social cost of carbon (B^{CO_2}).

$$B^{BC}_{y,t_0,t_1} = (Q^K_{y,t_0,t_1} \cdot Em^K_{BC}) \cdot B^{CO_2} \tag{5}$$

Phone charging benefits are calculated according to Equation (6) as the reduced expenditures on cell phone charging outside the home (E^{PC}_{y,t_0,t_1}).

$$B^{PC}_{y,t_0,t_1} = E^{PC}_{y,t_0,t_1} \tag{6}$$

Benefits of increased study time for girls are calculated according to Equation (7) as the change in study time $(\Delta GST_{y,t_0,t_1})$ multiplied by half of the unskilled minimum wage (B^{ST})

$$B^{GS}_{y,t_0,t_1} = \Delta GST_{y,t_0,t_1} \cdot B^{ST} \tag{7}$$

Benefits of increased study time for boys are calculated according to Equation (8) as the change in study time $(\Delta BST_{y,t_0,t_1})$ multiplied by half of the unskilled minimum wage (B^{ST}).

$$B^{BS}_{y,t_0,t_1} = \Delta BST_{y,t_0,t_1} \cdot B^{ST} \tag{8}$$

Benefits of asset ownership are calculated according to Equation (9) as the product of the change in asset ownership $(\Delta a_{y,t_0,t_1})$ and the consumer surplus (CS_a). This is calculated across all assets in the set A $(a \in A)$, which includes radios, fans, televisions, and refrigerators.

$$B^{A}_{y,t_0,t_1} = \sum_{a \in A} \Delta a_{y,t_0,t_1} \cdot CS_a \tag{9}$$

Benefits of improved electricity reliability are calculated according to Equation (10) as reductions in lost income resulting for electricity outages $(\Delta IL_{y,t_0,t_1})$.

$$B^{R}_{y,t_0,t_1} = \Delta IL_{y,t_0,t_1} \tag{10}$$

B. Model parameterizatio
B.1 Parameterization of basic EAD for Haiti

Table 8 provide the parameters used in the EAD calculations for Haiti. These parameters are based on information available in country-specific reports, country-level indicators, and the academic literature. Specific details on the calculation of certain parameters are provided here.

Electric lighting: Within the literature, household kerosene expenditure estimates vary—from an upper bound of 716 Haitian gourdes per month ($10 USD, or 6.5 percent of average monthly income) (Stuebi and Hatch, 2018) to a lower bound of 256 Haitian gourdes per month ($3.57 USD, or 2.3 percent of average monthly income) (IDB, 2016).[20] While these high kerosene expenditures suggest there is a high lighting component of the EAD in Haiti, this report takes a more conservative approach to the parametrization of benefits from electric lighting by adjusting the kerosene consumption reductions in Honduras (estimated from the household-level MTF survey data (World Bank and ESMAP, 2018)) to reflect Haiti's higher kerosene prices.

Cell phone charging: As with electric lighting, the literature reports high costs of cell phone charging outside the home—ranging from 4297-8235 gourdes/kWh (Stuebi and Hatch, 2018) or 284 gourdes per month (Schnitzer et al., 2014). This report takes a more conservative approach to the parameterization of benefits from cell phone charging inside the home by utilizing the expenditure parameter from Honduras (estimated from the household-level MTF survey data (World Bank and ESMAP, 2018)).

Table 8: Parameters used in simple EAD calculation, Haiti

Parameter	**Value**
Population (2016)	9,999,617
Electricity access (2016)	39 percent
Historical rate of electrification	0.4 percent
Househol d size	4.4 individuals
Kerosene expenditure savings	120 gourdes/year
Kerosene consumption savings	23.6 liters/year
Emissions factor (CO_2)	151.4 g/MJ kerosene
Emissions factor (black carbon)	0.012 g/MJ kerosene
Emissions factor (CH_4)	0.017 g/MJ kerosene
Emissions factor (N_2O)	0.055 g/MJ kerosene
Emissions factor (CO)	1.178 g/MJ kerosene
Emissions factor (organic carbon)	0.006 g/MJ kerosene
Global warming potential (CO_2)	1 g CO_2 equivalent/MJ
Global warming potential (black carbon)	5644.9 g CO_2 equivalent/MJ
Global warming potential (CH_4)	105.1 g CO_2 equivalent/MJ
Global warming potential (N_2O)	249.9 g CO_2 equivalent/MJ
Global warming potential (CO)	11.8 g CO_2 equivalent/MJ
Global warming potential (organic carbon)	-778.3 g CO_2 equivalent/MJ
Social cost of carbon	2.2 gourdes/kg
Study time (girls)	0 minutes/year
Study time (boys)	0 minutes/year
Cell phone charging expenditure savings	704.3 gourdes/year
Discount rate	12 percent , 5 percent

20. An exchange rate of 71 Haitian gourdes to 1 UDS is used throughout this report.

B.2 Parameterization of basic EAD for Honduras

Table 9 reports the parameters used in calculating the simple EAD for Honduras. Population and historical electricity access data come from country-level statistics (World Bank, 2018) to mirror the data inputs used in the EAD model for Haiti. The emissions parameters are calculated using the method outlined in Jeuland et al. (2018). The remaining parameters are estimated from the Honduras MTF survey data (World Bank and ESMAP, 2018) using basic multivariate regression controlling for household characteristics.

Table 9: Parameters used in simple EAD calculation, Honduras

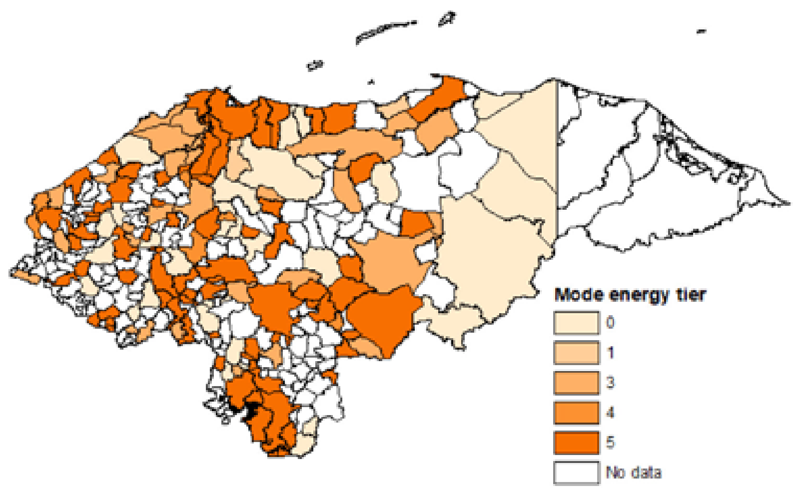
Parameter	**Value**
Population (2016)	9,112,867
Electricity access (2016)	82 percent
Historical rate of electrification	1.1 percent
Household size	4.5 individuals
Kerosene expenditure savings	388.4 lempiras/year
Kerosene consumption savings	23.6 liters/year
Emissions factor (CO_2)	151.4 g/MJ kerosene
Emissions factor (black carbon)	0.012 g/MJ kerosene
Emissions factor (CH_4)	0.017 g/MJ kerosene
Emissions factor (N_2O)	0.055 g/MJ kerosene
Emissions factor (CO)	1.178 g/MJ kerosene
Emissions factor (organic carbon)	0.006 g/MJ kerosene
Global warming potential (CO_2)	1 g CO_2equivalent/MJ
Global warming potential (black carbon)	5644.9 g CO_2equivalent/MJ
Global warming potential (CH_4)	105.1 g CO_2equivalent/MJ
Global warming potential (N_2O)	249.9 g CO_2equivalent/MJ
Global warming potential (CO)	11.8 g CO_2equivalent/MJ
Global warming potential (organic carbon)	-778.3 g CO_2equivalent/MJ
Social cost of carbon	0.74 lempira/kg
Study time (girls)	0 minutes/year
Study time (boys)	0 minutes/year
Cell phone charging expenditure savings	238 lempira/year
Discount rate	12 percent , 5 percent

B.3 Parameterization of extended EAD for Honduras

B.3.1 Most common electricity tier by municipality, Honduras

Figure 11 illustrates the most common tier of energy access in each municipality. The spatial distribution of the most common tier shows a similar distribution as does the average; however, it illustrates more clearly which municipalities have already reached tier 5 access for most of their inhabitants. In the extended EAD, the distribution of access across energy tiers is critical to the calculation; thus, this map demonstrates where the greatest potential gains to both electricity access and quality improvements exist within Honduras.

Figure 11: Most common energy tier by municipality, Honduras



B.3.2 Asset ownership across tiers

The tiers of energy access in Honduras have tangible implications for levels of electricity access households enjoy. One example of this is the distribution of asset ownership across energy tiers in Honduras.

Table 10 shows this distribution, demonstrating that electricity-using assets are generally owned by households in higher energy tiers. While this is not an indication that electricity access causes asset ownership, the trends do suggest that lower tier households may not have the electricity capacity or reliability to justify ownership of energy-intensive assets. Panel A shows the distribution among rural households. Lower energy tier households may own radios; however, ownership of other assets such as fans, televisions, and refrigerators are quite uncommon. Moving up through the tiers leads to higher rates of ownership of these larger assets. This is especially apparent for Tier 3 households, where the percentage of households owning fans nearly doubles and the percentage of households owning refrigerators more than triples compared to tier 2 households. Panel B shows the distribution of asset ownership by energy tier for urban households in Honduras. Here the same trends of asset ownership are observed; however, in comparison to rural households, overall rates of asset ownership are higher across all tiers.

Table 10: Asset ownership by tier, Honduras

	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Panel A: Rural						
Radio	0.37 [36.2]	0.57 [56.1]	0.49 [43.5]	0.49 [46.6]	0.50 [48.5]	0.54 [52.3]
Fan	0.02 [1.7]	0.01 [1.2]	0.22 [15.9]	0.72 [43.3]	0.61 [41.7]	0.55 [37.7]
Television	0.09 [8.6]	0.09 [7.3]	0.62 [60.9]	0.88 [76.4]	0.96 [80.6]	0.85 [73.4]
Refrigerator	0.02 [1.7]	0.01 [1.2]	0.19 [18.8]	0.70 [63.9]	0.63 [62.1]	0.63 [58.2]
Panel B: Urban						
Radio	0.17 [17.2]	0.38 [37.5]	0.46 [45.7]	0.52 [48.5]	0.49 [47.2]	0.59 [56.9]
Fan	0.21 [20.7]	0.25 [12.5]	0.77 [45.7]	1.36 [75.0]	1.51 [76.4]	1.26 [71.5]
Television	0.21 [20.7]	0.38 [25.0]	0.71 [60.0]	1.36 [92.7]	1.33 [94.4]	1.34 [91.2]
Refrigerator	0.10 [10.3]	0.13 [12.5]	0.49 [48.6]	0.88 [80.1]	0.92 [81.3]	0.87 [80.1]

Results reported as mean number of assets owned per tier [percent of households that own at least one].

B.3.3 Extended EAD parameters, Honduras

Table 11 and Table 12 show the parameters used in the calculation of the extended EAD for Honduras. While the data sources are consistent with those used in the simple EAD, the household tier designation available in the MTF data allow for more nuanced analysis of benefits across tiers, which incorporates not only access but also other characteristics of electricity—reliability, quality, duration, legality, capacity etc.—into the EAD. Furthermore, given that households at higher energy tiers may also utilize their electricity in ways that differ from those with basic access (e.g., use electricity for productive use, invest in energy-intensive assets), additional benefits of electricity access are incorporated into the extended EAD for Honduras.

Table 11: Parameters used in extended EAD calculation, urban Honduras

		Value				
Parameter	**Unit**	**Tier 1**	**Tier 2**	**Tier 3**	**Tier 4**	**Tier 5**
Population (2016)	Millions of individuals	9.11	9.11	9.11	9.11	9.11
Electricity access (2016)	percent	97.66	97.02	94.2	56.49	44.88
Historical rate of electrification	percent	0.02	0.02	0.02	0.02	0.02
Household size	individuals	4.3	4.3	4.3	4.3	4.3
Number of children	girls/household	0.63	0.63	0.63	0.63	0.63
Number of children	boys/household	0.67	0.67	0.67	0.67	0.67
Keroseneexpenditure savings	lempiras/year	388.4	0	0	0	0
Kerosene consumption savings	liters/year	23.6	0	0	0	0
Emissions factor (CO_2)	g/MJ kerosene	151.4	0	0	0	0
Emissions factor (black carbon)	g/MJ kerosene	0.012	0	0	0	0
Emissions factor (CH_4)	g/MJ kerosene	0.017	0	0	0	0
Emissions factor (N_2O)	g/MJ kerosene	0.055	0	0	0	0
Emissions factor (CO)	g/MJ kerosene	1.178	0	0	0	0
Emissions factor (organic carbon)	g/MJ kerosene	0.006	0	0	0	0
Global warming potential (CO_2)	g co2 equivalent/MJ	1	0	0	0	0
Globalwarming potential (black carbon)	g co2 equivalent/MJ	5644.9	0	0	0	0
Global warming potential (CH_4)	g co2 equivalent/MJ	105.1	0	0	0	0
Global warming potential (N_2O)	g co2 equivalent/MJ	249.9	0	0	0	0
Global warming potential (CO)	g co2 equivalent/MJ	11.8	0	0	0	0
Global warming potential (organic carbon)	g co2 equivalent/MJ	-778.3	0	0	0	0
Social cost of carbon	lempira/kg	0.74	0.74	0.74	0.74	0.74
Study time (girls)	minutes/year	0	0	0	0	0
Study time (boys)	minutes/month	0	0	403.5	0	0
Unskilled wage rate	lempira/hour	38.1	38.1	38.1	38.1	38.1
Cell phone charging expenditure savings	lempira/year	230.08	100.68	0	0	0
Radio ownership	number of radios	0.37	0	0	0	0
Radio consumer surplus	lempira/year	107.8	0	0	0	0
Fan ownership	number of fans	0	0.66	0	0	0
Fan consumer surplus	lempira/year	0	36.6	0	0	0
TV ownership	number of TVs	0	0	0.31	0	0
TV consumer surplus	lempira/year	0	0	411.1	0	0
Refrigerator ownership	number of refrigerators	0	0.49	0.25	0	0
Refrigerator consumer surplus	lempira/year	0	560.1	560.1	0	0
Reduced income loss	lempira/year	0	0	0	0	529.9
Elasticity of demand for durable goods		-1.5	-1.5	-1.5	-1.5	-1.5
Discount rate	percent	12	12	12	12	12

Table 12: Parameters used in extended EAD calculation, rural Honduras

Parameter	Unit	Value				
		Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Population (2016)	Millions of individuals	9.11	9.11	9.11	9.11	9.11
Electricity access (2016)	percent	69.63	64.42	60.04	38.76	32.21
Historical rate of electrification	percent	1.4	1.4	1.4	1.4	1.4
Household size	individuals	4.7	4.7	4.7	4.7	4.7
Number of children	girls/household	0.82	0.82	0.82	0.82	0.82
Number of children	boys/household	0.88	0.88	0.88	0.88	0.88
Keroseneexpenditure savings	lempiras/year	388.4	0	0	0	0
Kerosene consumption savings	liters/year	23.6	0	0	0	0
Emissions factor (CO_2)	g/MJ kerosene	151.4	0	0	0	0
Emissions factor (black carbon)	g/MJ kerosene	0.012	0	0	0	0
Emissions factor (CH_4)	g/MJ kerosene	0.017	0	0	0	0
Emissions factor (N_2O)	g/MJ kerosene	0.055	0	0	0	0
Emissions factor (CO)	g/MJ kerosene	1.178	0	0	0	0
Emissions factor (organic carbon)	g/MJ kerosene	0.006	0	0	0	0
Global warming potential (CO_2)	g co2 equivalent/MJ	1	0	0	0	0
Globalwarming potential (black carbon)	g co2 equivalent/MJ	5644.9	0	0	0	0
Global warming potential (CH_4)	g co2 equivalent/MJ	105.1	0	0	0	0
Global warming potential (N_2O)	g co2 equivalent/MJ	249.9	0	0	0	0
Global warming potential (CO)	g co2 equivalent/MJ	11.8	0	0	0	0
Global warming potential (organic carbon)	g co2 equivalent/MJ	-778.3	0	0	0	0
Social cost of carbon	lempira/kg	0.74	0.74	0.74	0.74	0.74
Study time (girls)	minutes/year	0	0	124.5	0	0
Study time (boys)	minutes/year	0	0	0	0	0
Unskilled wage rate	lempira/hour	38.1	38.1	38.1	38.1	38.1
Cell phone charging expenditure savings	lempira/year	230.08	100.68	0	0	0
Radio ownership	number of radios	0.13	0	0	0	0
Radio consumer surplus	lempira/year	107.8	0	0	0	0
Fan ownership	number of fans	0	0.25	0	0	0
Fan consumer surplus	lempira/year	0	36.6	0	0	0
TV ownership	number of TVs	0	0.6	0	0	0
TV consumer surplus	lempira/year	0	411.1	0	0	0
Refrigerator ownership	number of refrigerators	0	0.17	0.36	0	0
Refrigerator consumer surplus	lempira/year	0	560.1	560.1	0	0
Reduced income loss	lempira/year	0	0	0	25	31
Elasticity of demand for durable goods		-1.5	-1.5	-1.5	-1.5	-1.5
Discount rate	percent	12	12	12	12	12

To elicit the parameters used in the Honduran EAD calculations, the following regression (Equation (11)) was run

$$Y = \alpha + \beta tier + X + \varepsilon \tag{11}$$

where
Y is the benefit parameter of interest (i.e., household kerosene expenditure, household kerosene consumption, cell phone charging expenditures, boy/girl study time, number of radios/fans/televisions/refrigerators owned, income lost due to electricity outages); tier is the energy tier assigned to the household; and X is a vector of control variables that includes the gender and age of the household head, the household size, the number of children in the household under the age of 5, the household's yearly reported income, and an asset index (generated using the polychoricpca command in Stata (Kolenikvo, 2016)). Standard errors were clustered at the municipality level.

For the basic EAD, this regression was run (for the relevant benefits) on the entire sample of households, treating tier as a binary indicator for attaining at least tier 1 electricity. For the extended EAD, this regression was run for the urban and rural subsamples separately. Furthermore, it was run on tiered-subsections, to treat the tier variable as an indicator and not a categorical variable. Finally, if households did not answer a given question (i.e., they did not report income lost due to electricity outages because earlier in the survey they reported that they did not use electricity for income generation), a zero was imputed.

There are two exceptions to this method of parameterization. First, to savings from reduced emissions were calculated and valued following the method illustrated in Jeuland et al. (2018). Second, given the small sample of rural households experiencing income generation loss as a result of disruptions in electricity access, the following regression (Equation (12)) was run on the sample of rural households

$$Y = \alpha + \beta_1 t_1 + \beta_2 t_2 + \beta_3 t_3 + \beta_4 t_4 + \beta_5 t_t + X + \varepsilon \tag{12}$$

where
Y takes a value of one if households report income loss due to electricity disruptions; t_i is an indicator for energy tier i (where $i \in \{1,2,3,4,5\}$; and X is a vector of control variables that includes the gender and age of the household head, the household size, the number of children in the household under the age of 5, the household's yearly reported income, and an asset index (generated using the polychoricpca command in Stata (Kolenikvo, 2016)). Standard errors were clustered at the municipality level.

The difference in coefficients β_3 and β_4 and coefficients β_4 and β_5 were multiplied by the mean income loss reported (3122 lempiras) to calculate the reliability gains associated with energy tiers 4 and 5 for rural households.

B.4 Estimating consumer surplus

To calculate consumer surplus, first, price and quantity data for each asset are obtained for the region (MEF, 2017)[21.] Second, an elasticity of demand is assumed—in this report an elasticity of demand of -1.5 is used, reflecting the long-run elasticity of durable goods (Casarin and Delfino 2011; Dergiades and Tsoulfidis, 2008). Third, a functional form is applied to the demand for each asset—in this report the demand curve is assumed to be convex, yielding a constant elasticity across the entire curve (Boardman et al., 2017). Finally, the area under the demand curve and above the market price for each asset is calculated, yielding the consumer surplus of acquiring each new asset.

21. Price and quality data from Panama are utilized in this exercise, as the data were unavailable for Honduras.

C. Sensitivity analysis

Here the results of the simple EAD for Haiti and Honduras and the extended EAD for Honduras (under all three electrification scenarios) using a discount rate of 5 percent and using no discounting are presented in table form. These figures are designed to provide additional context for the bounds of the EAD, as the calculation represents a parameterized estimate. With the exception of the discount rate, all parameters and methods used in these models are identical to the analysis in the main report.

Table 13: Simple EAD by benefit type, Haiti, 5 percent discount rate

Cumulative Dividend		**percent of total**
Lighting expenditure (billion gourdes)	30.52	55.0 percent
Combined emissions (million tons)	5.87	
Combined emissions (billion gourdes)	6.37	11.5 percent
Cell phone expenditure (billion gourdes)	18.65	33.6 percent
Dividend in 2016	**1.74**	
Lighting expenditure (billion gourdes)	0.17	55.0 percent
Combined emissions (million tons)	0.36	
Combined emissions (billion gourdes)	1.06	11.5 percent
Cell phone expenditure (billion gourdes)	30.52	33.6 percent

Table 14: Simple EAD by benefit type, Haiti, no discounting

Cumulative Dividend		**percent of total**
Lighting expenditure (billion gourdes)	61.93	48.1 percent
Combined emissions (million tons)	13.15	
Combined emissions (billion gourdes)	29.06	22.6 percent
Cell phone expenditure (billion gourdes)	37.84	29.4 percent
Dividend in 2016		
Lighting expenditure (billion gourdes)	1.74	48.1 percent
Combined emissions (million tons)	0.37	
Combined emissions (billion gourdes)	0.82	22.6 percent
Cell phone expenditure (billion gourdes)	1.06	29.4 percent

Table 15: Simple EAD by benefit type, Honduras, 5 percent discount rate

Cumulative Dividend		**percent of total**
Lighting expenditure (billion lempiras)	0.96	54.9 percent
Combined emissions (thousand tons)	365.87	
Combined emissions (billion lempiras)	0.20	11.5 percent
Cell phone expenditure (billion lempiras)	0.59	33.6 percent
Dividend in 2016		
Lighting expenditure (billion lempiras)	0.12	54.9 percent
CO_2 emissions (tons)	32.87	
CO_2 emissions (billion lempiras)	0.02	11.5 percent
Cell phone expenditure (billion lempiras)	0.07	33.6 percent

Table 16: Simple EAD by benefit type, Honduras, no discounting

Cumulative Dividend		**percent of total**
Lighting expenditure (billion lempiras)	1.30	54.9 percent
CO_2 emissions (tons)	820.19	
CO_2 emissions (billion lempiras)	0.61	11.5 percent
Cell phone expenditure (billion lempiras)	0.80	33.6 percent
Dividend in 2016		
Lighting expenditure (billion lempiras)	0.12	54.9 percent
CO_2 emissions (tons)	73.69	
CO_2 emissions (billion lempiras)	0.06	11.5 percent
Cell phone expenditure (billion lempiras)	0.07	33.6 percent

Table 17: Extended EAD by benefit type, Honduras, 5 percent discount rate

	Universal Tier 5	Universal Tier 3	Mixed Tiers 3 and 5
Cumulative Dividend			
Lighting expenditure (million lempiras)	929.2	929.2	929.2
Combined emissions (tons)	35.1	35.1	35.1
Combined emissions (million lempiras)	458.4	458.4	458.4
Cell phone expenditure (million lempiras)	974.3	974.3	974.3
Radio (number of radios)	501807.8	501807.8	501807.8
Radio (million lempiras)	111.9	37.7	111.9
Fan (number of fans)	534104.3	534104.3	534104.3
Fan (million lempiras)	36.5	36.5	36.5
TV (number of TVs)	1237078.8	1237078.8	1237078.8
TV (million lempiras)	903.1	903.1	903.1
Refrigerator (number of refrigerators)	1080356.2	1080356.2	1080356.2
Refrigerator (million lempiras)	1291.4	1291.4	1291.4
Girl's study time (hours)	2712844.9	2712844.9	2712844.9
Girl's study time (millions of lempiras)	91.4	91.4	91.4
Boy's study time (hours)	4076223.9	4076223.9	4076223.9
Boy's study time (millions of lempiras)	62.8	62.8	62.8
Income not lost (million lempiras)	5443.9	0.0	5000.1
Yearly Dividend			
Lighting expenditure (million lempiras)	113.0	113.0	113.0
Combined emissions (tons)	2739.9	2739.9	2739.9
Combined emissions (million lempiras)	54.8	54.8	54.8
Cell phone expenditure (million lempiras)	112.4	112.4	112.4
Radio (number of radios)	47537.9	47537.9	47537.9
Radio (million lempiras)	12.4	4.8	12.4
Fan (number of fans)	17286.3	17286.3	17286.3
Fan (million lempiras)	3.9	3.9	3.9
TV (number of TVs)	39851.1	39851.1	39851.1
TV (million lempiras)	91.8	91.8	91.8
Refrigerator (number of refrigerators)	35260.6	35260.6	35260.6
Refrigerator (million lempiras)	127.5	127.5	127.5
Girl's study time (hours)	83949.5	83949.5	83949.5
Girl's study time (millions of lempiras)	9.4	9.4	9.4
Boy's study time (hours)	148951.8	148951.8	148951.8
Boy's study time (millions of lempiras)	5.5	5.5	5.5
Income not lost (million lempiras)	374.3	0.0	339.8

Table 18: Extended EAD by benefit type, Honduras, no discounting

	Universal Tier 5	Universal Tier 3	Mixed Tiers 3 and 5
Cumulative Dividend			
Lighting expenditure (million lempiras)	1253.6	1253.6	1253.6
Combined emissions (thousand tons)	78.7	78.7	78.7
Combined emissions (million lempiras)	640.9	640.9	640.9
Cell phone expenditure (million lempiras)	1369.0	1369.0	1369.0
Radio (number of radios)	501807.8	501807.8	501807.8
Radio (million lempiras)	147.5	50.1	147.5
Fan (number of fans)	534104.3	534104.3	534104.3
Fan (million lempiras)	54.5	54.5	54.5
TV (number of TVs)	1237078.8	1237078.8	1237078.8
TV (million lempiras)	1376.9	1376.9	1376.9
Refrigerator (number ofrefrigerators)	1080356.2	1080356.2	1080356.2
Refrigerator (million lempiras)	2018.6	2018.6	2018.6
Girl's study time (hours)	2712844.9	2712844.9	2712844.9
Girl's study time (millions of lempiras)	137.6	137.6	137.6
Boy's study time (hours)	4076223.9	4076223.9	4076223.9
Boy's study time (millions of lempiras)	105.6	105.6	105.6
Income not lost (million lempiras)	9783.4	0.0	9003.7
Yearly Dividend			
Lighting expenditure (million lempiras)	113.0	113.0	113.0
Combined emissions (thousand tons)	5852.0	5852.0	5852.0
Combined emissions (million lempiras)	57.6	57.6	57.6
Cell phone expenditure (million lempiras)	112.4	112.4	112.4
Radio (number of radios)	47537.9	47537.9	47537.9
Radio (million lempiras)	12.4	4.8	12.4
Fan (number of fans)	17286.3	17286.3	17286.3
Fan (million lempiras)	3.9	3.9	3.9
TV (number of TVs)	39851.1	39851.1	39851.1
TV (million lempiras)	91.8	91.8	91.8
Refrigerator (number of refrigerators)	35260.6	35260.6	35260.6
Refrigerator (million lempiras)	127.5	127.5	127.5
Girl's study time (hours)	83949.5	83949.5	83949.5
Girl's study time (millions of lempiras)	9.4	9.4	9.4
Boy's study time (hours)	148951.8	148951.8	148951.8
Boy's study time (millions of lempiras)	5.5	5.5	5.5
Income not lost (million lempiras)	374.3	0.0	339.8

D. Evidence from the literature

Table 19: Evidence on key EAD parameters from the literature

Related Studies	Country	Technology (Estimated Tier)	Outcome of Interest	Results
Lighting				
Komatsu et al., 2011	Bangladesh	Solar home systems (Tier 3)	Kerosene for lighting	70 percent reduction in kerosene consumption
Lee et al., 2016	Kenya	Electric grid (Tier 5) Solar home systems (Tier 2/3)	Kerosene for lighting	Grid-connected and SHS households spend about the same amount on kerosene as unconnected households
Lenz et al., 2017	Rwanda	Low voltage electric grid (Tier 3-4)	Electric lighting	Hours with lighting triples for connected households
Emissions				
Barron & Torero, 2017	El Salvador	Grid extension and intensification (Tier 5)	Indoor overnight $PM_{2.5}$ concentration	Concentration was 66 percent lower in households randomly encouraged to get a grid connection
Lenz et al., 2017	Rwanda	Low voltage electric grid (Tier 3-4)	Self-reported air quality	Self-reported indoor air quality is better among electrified households
Communication				
Komatsu et al., 2011	Bangladesh	Solar home systems (Tier 3)	Phone charging	Reduction in cell phone charging outside the home
Lenz et al., 2017	Rwanda	Low voltage electric grid (Tier 3-4)	Phone access	Electrified households have 0.27 more mobile phones and use phones more frequently
Education				
Komatsu et al., 2011	Bangladesh	Solar home systems (Tier 3)	Study time	Extended potential time for studying by 1-3 hours per day
Gustavsson & Ellegard, 2004	Zambia	Solar home systems (Tier 3)	Study time	89 percent of households with SHS report that children can study at night compared to 42 percent of non-SHS households
Grogran, 2016	Colombia	Hydroelectric dams (Tier 5)	Children completing 1 year of school by age 8	Increases by 9-10 percent for each 0.1 increase in fraction of electrified households
Lenz et al., 2017	Rwanda	Low voltage electric grid (Tier 3-4)	Study time	Overall study time does not change, but evening study time increases by 19-44 minutes among electrified households
Squires, 2015	Honduras	Grid electricity (Tier 4-5)	Number of students completing school	6.5 percentage point decrease in school completion in electrified areas
Lipscomb et al., 2013	Brazil	Hydroelectric dams (Tier 5)	Educational attainment	Full electrification increases educational attainment by 2 years
Asset ownership/use				
Gustavsson & Ellegard, 2004	Zambia	Solar home systems (Tier 3)	Appliance ownership	Higher ownership of electricity-intensive assets such as TV and refrigerator among SHS households
Lee et al., 2016	Kenya	Electric grid (Tier 5) Solar home systems (Tier 2/3)	Appliance ownership	Connected households own more appliances than SHS and unconnected households
Economic development				
Lipscomb et al., 2013	Brazil	Hydroelectric dams (Tier 5)	HDI Housing values	Achieving full electrification is associated with a 9-11 point HDI increase 3.8 percent increase in housing values

cont. Table 19: Evidence on key EAD parameters from the literature

Related Studies	Country	Technology (Estimated Tier)	Outcome of Interest	Results
Productive use				
Lenz et al., 2017	Rwanda	Low voltage electric grid (Tier 3-4)	Income generation	No effect of electrification on income-generating activities
Health				
Barron & Torero, 2017	El Salvador	Grid extension and intensification (Tier 5)	Acute respiratory infections among children	8-14 percentage point reduction among children in households randomly encouraged to get a grid connection
Time use changes				
Grogan & Sadanand, 2013	Nicaragua	Electricity access (unknown)	Work outside the home Time spent collecting firewood	Women in electrified households are 23 percent more likely to work outside the home; the effect for men is insignificant Negative relationship between time spent collecting firewood and electricity access for men and women
Squires, 2015	Honduras	Grid electricity (Tier-4 5)	Female employment	Higher rates of employment and hours worked among females in electrified municipalities
Lipscomb et al., 2013	Brazil	Hydroelectric dams (Tier 5)	Employment	Full electrification yields a 17-18 percentage point increase in probability of employment

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