Journal of Benefit-Cost Analysis (2024), 1–33
doi:10.1017/bca.2024.14

CAMBRIDGE
UNIVERSITY PRESS

ARTICLE

Estimating Lost Dividends from Incomplete Energy Access Transitions

Emily L. Pakhtigian[1], Marc Jeuland[2], Subhrendu K. Pattanayak[3] and Jonathan Phillips[4]

[1]School of Public Policy, Pennsylvania State University, University Park, PA, USA
[2]Sanford School of Public Policy and Duke Global Health Institute, Duke University, Durham, NC, USA
[3]Sanford School of Public Policy, Department of Economics, and Duke Global Health Institute, Duke University, Durham, NC, USA
[4]Nicholas Institute for Environmental Policy Solutions, Duke University, Durham, NC, USA
Corresponding author: Emily L. Pakhtigian; Email: emilypakhtigian@psu.edu

Keywords: electrification; energy access; energy transitions; Honduras; multi-tier framework

JEL Codes: D61; O13; Q48

Abstract

Energy access is often considered a catalyst for development. Yet, the binary classification of household electrification misses important variation in service quality and in how households use electricity. To examine the benefits of household electrification and illustrate the importance of using more nuanced classifications of energy access, this article develops a metric called the Energy Access Dividend (EAD), which quantifies the electrification benefits forgone due to slow and incomplete energy transitions. This framework is flexible, allowing for the estimation of a variety of electrification benefits such as reduced lighting and cell phone charging expenditures, environmental improvements, time use and asset ownership changes, and improvements associated with productive energy use. To demonstrate the applicability of this framework, we calculate the EAD for several proposed electrification trajectory alternatives in Honduras. We find that in Honduras, a country with high rates of basic electricity access, achieving immediate universal, high-quality electricity would generate nearly $697 million in benefits over the period leading up to 2050. We also estimate the EADs associated with more limited immediate electrification as well as geographically based electrification scenarios, demonstrating that these calculations can inform priorities for energy policy design.

1. Introduction

Access to modern energy services is seen as a conduit to social well-being and economic opportunity and growth. The sustainable development goals (SDGs) recognize universal electrification as a key component of sustainable global development (International Energy Agency, 2017). SDG 7 focuses on ensuring energy access that is affordable, reliable, sustainable, and modern, and other SDGs – those targeting poverty reductions, improvements in education and healthcare, and gender equality, among others – would be greatly aided by, or are reliant upon, enhanced energy access (McCollum *et al.,* 2018; Jeuland *et al.,* 2021).[1]

SDG 7 sets ambitious targets: Universal electricity access; increased shares of renewables for energy generation and improved energy efficiency; and coordination across countries to facilitate clean energy access, including infrastructure and technology research and development (International Energy Agency, 2017). Despite progress made toward these goals, attaining them by 2030 will require substantial increases in the speed of current energy access transitions, declines in installed equipment costs, and policy changes that facilitate investment in the off-grid sector (World Bank *et al.,* 2020). Moreover, while the framing of SDG 7 acknowledges the multiple dimensions of energy access, one of its primary indicators – and the one that gets the most attention – is simply the electrified proportion of the population. In this article, we demonstrate the importance of a richer conceptualization of electricity access – including capacity, reliability, availability, and other characteristics.

There is increasing evidence and agreement that the binary access indicator – if a household is electrified or not – overlooks important nuances related to the quality of that access. For example, while electricity can improve health through channels such as refrigeration, temperature control, sterilization, information access, and accessibility of less polluting cooking technologies (Adair-Rohani *et al.,* 2013; Irwin *et al.,* 2020), this is only possible if electricity supply to households can support such technologies and power outages are limited (Gertler *et al.,* 2017). In other, non-health, sectors, moving beyond a binary characterization of household electrification is necessary to describe the economic (Grogan & Sadanand, 2013; Chakravorty *et al.,* 2014; Fetter & Usmani, 2020) and social (Jacobson, 2007; Boateng *et al.,* 2020) dimensions of electrification. Furthermore, assessing energy access without consideration of household demand and affordability provides an incomplete characterization, since users may have electricity access but still be unable or unwilling to pay at the quality or reliability levels needed to substantially improve well-being (Kemmler, 2007; Winkler *et al.,* 2011; Sagebiel & Rommel, 2014; Blimpo & Cosgrove-Davies, 2019; Lee *et al.,* 2020*b*). Indeed, ignoring these nuances may be part of the reason why a simple characterization of access to electricity has been found to have ambiguous or inconclusive impacts on economic development in many prior studies and reviews (Bernard, 2012; Peters & Sievert, 2016; Bos *et al.,* 2018; Morrissey, 2019; Bayer *et al.,* 2020; Jeuland *et al.,* 2021).

One example of an approach to a more nuanced classification of energy access is the multi-tier framework (MTF) developed by the World Bank's Energy Sector Management Assistance Program (ESMAP). Under the MTF framework, household electrification is characterized by peak capacity, availability, reliability, quality, affordability, legality, and health and safety (Bhatia & Angelou, 2015). The MTF uses a six-tier classification system ranging from tier 0 (no electricity access) to tier 5 (consistent, reliable electricity for all household electrification needs). Although specific aspects of the MTF have been critiqued, especially with respect to how the various dimensions should be aggregated into an overall electricity access tier (Groh *et al.,* 2016), the framework is clearly more sophisticated than a simple binary indicator. As such, the MTF allows for potentially sharper insights into how electrification resources could be allocated and targeted to improve the delivery of specific energy services (Bhatia & Angelou, 2015; Boateng *et al.,* 2020).

[1] Abbreviations used in this article include Business-as-Usual (BAU); Energy Access Dividend (EAD); Multi-Tier Framework (MTF); and Sustainable Development Goals (SDGs).

In this article, we demonstrate the implications of moving from a simple binary to a tiered characterization of energy access for quantifying the benefits of the SDG 7 definition of universal access to modern electricity. First, we outline a new approach to estimating the benefits along various electrification trajectories, which we call the Energy Access Dividend (EAD), that takes into account the differing dimensions of electricity access and the potential benefits of moving up electricity access tiers. The EAD provides a flexible framework for electrification benefits estimation that can be adjusted to meet the needs of different contextual settings and policy goals. Second, we demonstrate an application of the framework: Specifically, we use estimates from the literature as well as a cross-sectional household survey to parameterize the EAD model and derive EAD estimates across three policy scenarios for Honduras. Accordingly, to the best of our knowledge, we present the first operationalization of the EAD to estimate the benefits of projected electrification trajectories in a developing country context. Finally, we discuss the ways in which improved causal estimates of various benefits of electrification would allow for better estimation of the EAD and further insights for energy policy globally.

2. Modeling the EAD

The EAD provides a framework to quantify the forgone dividends inherent in a country's BAU transition to universal electrification (SEforALL *et al.,* 2017; Marzolf *et al.,* 2019). That is, using a specific characterization of energy access within a country (either based on binary indicators of access or categorical ones such as proposed in the MTF), the EAD equals the dividends that would result from specific scenarios of immediate improved electrification status, over and above those already being realized under the BAU electrification trajectory. Thus, these calculations likely correspond to an upper bound on the short-term consumption benefits and reduced reliability losses provided by policy interventions that would accelerate the electrification trajectory. To the extent that those benefits grow over time and some categories of benefits are omitted due to lack of data or other factors, though, these values could be deemed conservative.[2] The timelines used in these calculations allow for comparisons of the status quo to a variety of alternative transitions. The EAD framework is flexible and adaptable; depending on the context, energy transition scenario, and data available, it can be applied to assess the relative dividends provided by different electrification trajectories. For example, one can compare the value of policy interventions aimed at prioritizing basic universal electrification rapidly to that obtained from enhancing the quality of access of those already having electricity connections that are nonetheless unreliable or otherwise deficient.

We operationalize the concept of the EAD to assess the forgone benefits of a country's current pace of electrification compared to alternative electrification scenarios. We calculate the EAD as the sum of electrification benefits across all tiers ($t = 0, \ldots, T_s$), years ($y = 1, \ldots, Y$), and rural/urban geographies ($G = \{U, R\}$) according to

[2] There is limited empirical evidence on the long-term benefits of electrification (Van de Walle *et al.,* 2017; Lee *et al.,* 2020a), which motivates the approach taken in our calculations.

https://doi.org/10.1017/bca.2024.14 Published online by Cambridge University Press

$$EAD = \sum_{t=0}^{T_s} \sum_{y=1}^{Y} \sum_{\forall g \in G} (1+\delta)^{-y} \left(B_{t_0,\mathrm{t}_1 = T_{s,y,g}} \right) \cdot f_{t_0,t_1=T_{s,y,g}} \cdot H_{y,g}. \tag{1}$$

Here, $B_{t_0,t_1=T_s,y,g}$ corresponds to the benefits of electricity access accrued between a household's initial tier (t_0) and maximum tier under consideration ($t_1 = T_s$) in year y and geography g; $f_{t_0,t_1=T_s,y,g}$ is the fraction of households in each initial tier (t_0) who have not achieved the maximum tier $t_1 = T_s$ in year y and geography g; and $H_{y,g}$ is the total number of households in year y and geography g. The maximum tier under consideration ($t_1 = T_s$) varies based on the alternative electrification scenario used for calculating the EAD; for example, for a scenario including immediate, comprehensive electrification, T_s would be equal to the highest electrification tier. We calculate the present value of these benefits over the evaluative time horizon using a discount rate of δ. There are various benefits to electricity access that could be included in the EAD calculation, and these can be updated according to what is appropriate in a specific context or based on data availability.

Specifying where in the tier sequence each benefit accrues is especially important for the benefits calculations. While some benefits are obtained once a household gains basic tier-one energy access, others will require higher tier access. Table 1 presents Bhatia and Angelou's (2015) conception of the tier-wise technical characteristics and technology required to achieve these characteristics. Based on these specifications, households can be classified into tiers of electricity access. Upon classification, it becomes an empirical – and context-specific – question as to what types of benefits can be enjoyed given the electricity characteristics. For example, simple electric appliances such as radios and phone chargers may require only tier 1 electrification, whereas more energy-intensive appliances such as televisions and especially refrigerators may require higher tier access.[3]

2.1. Alternative estimation using consumer surplus

An alternative approach to the EAD, which seeks to estimate the overall benefits of electrification based on the demand curve for electricity, is to calculate the aggregate consumer surplus associated with moving across electricity tiers. We demonstrate this alternative by calculating the following:

$$EAD = \sum_{t=0}^{T_s} \sum_{y=1}^{Y} \sum_{\forall g \in G} (1+\delta)^{-y} \left(CS_{t_0,t_1=T_{s,y,g}} + SB_{t_0,\mathrm{t}_1,y,g} \right) \cdot f_{t_0,t_1=T_{s,y,g}} \cdot H_{y,g}. \tag{2}$$

All terms in Equation (2) are as defined above; $CS_{t_0,t_1=T_s,y,g}$ refers to the consumer surplus associated with moving between a household's initial tier (t_0) and maximum tier under consideration ($t_1 = T_s$) in year y and geography g, and $SB_{t_0,t_1,y,g}$ refers to social benefits not counted in consumer surplus associated with moving between a household's initial tier (t_0) and maximum tier under consideration ($t_1 = T_s$) in year y and geography g.

[3] We provide a context-specific example for the case of Honduras later in the paper. Supplementary Table A1 outlines the changes in household appliance use across tiers in the Honduran context based on parameterization from the MTF household survey for Honduras (Luzi *et al.*, 2020) (see Section 4).

https://doi.org/10.1017/bca.2024.14 Published online by Cambridge University Press

Table 1. *Characteristics and technology access across tiers*

	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Characteristics	– 12 daily watt–hours (Wh) – 4 hours of daytime access – 1 hour of evening access	– 200 daily Wh – 4 hours of daytime access – 2 hours of evening access	– 1 daily kilowatt hour (kWh) – 8 hours of daytime access – 3 hours of evening access – Costs do not exceed 5% of household income	– 3.4 daily kWh – 16 hours of daytime access – 4 hours of evening access – Less than 14 disruptions per week – Costs do not exceed 5% of household income – Legal connection – Low risk of accidents	– 8.2 daily kWh – 23 hours of daytime access – 4 hours of evening access – Less than 3 disruptions per week – Costs do not exceed 5% of household income – Legal connection – Low risk of accidents
Technology	– Solar lanterns	– Solar home system – Rechargeable battery	– Solar home systems – Generator – Mini-grid	– Generator – Mini-grid – Grid	– Large generator – Mini-grid – Grid

Source: Compiled and summarized from Bhatia and Angelou (2015). Numbers presented are minimum values (e.g., 12 daily Wh for tier 1 access is a minimum of 12 daily Wh).

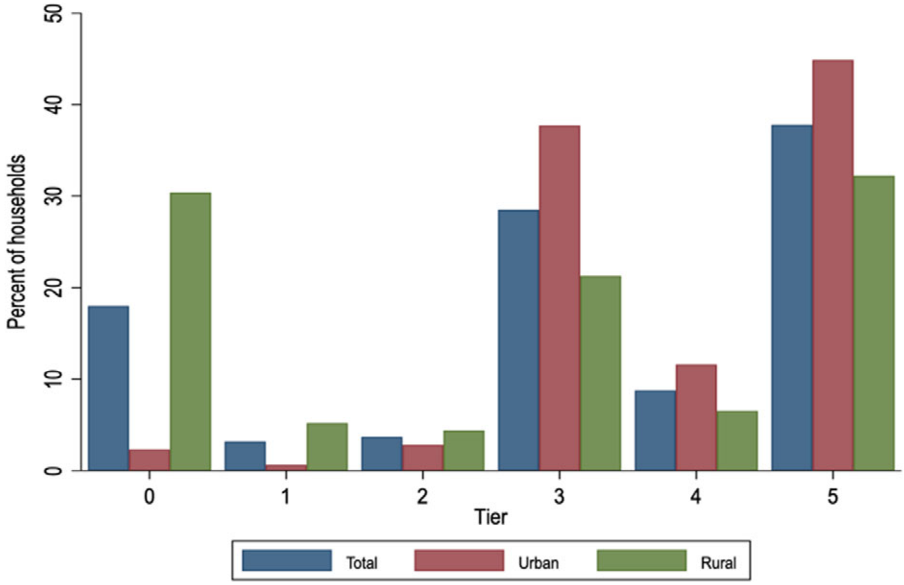

Figure 1. *Distribution across MTF energy access tiers among all (blue), urban (red), and rural (green) households in Honduras in 2017.* Source: *Authors' calculations using Honduras MTF survey data (Luzi et al., 2020).*

3. Honduras as a case study

We demonstrate the application of the EAD in Honduras due to the availability of relevant data and the considerable variation in the quality of household energy access in that country. This latter variation facilitates the examination of the differences in results that stem from using unidimensional and multidimensional characterizations of electricity access.

3.1. Electricity access in Honduras

Indeed, while the reported rate of household electrification in Honduras was nearly 92% in 2018 (World Bank *et al.,* 2020), household-level survey data from the country reveals considerable variation in electricity access according to the MTF tier definitions. Figure 1 displays the MTF tiers among a representative sample of 2815 households across Honduras (Luzi *et al.,* 2020). Within this household sample, approximately 18% of households are classified as tier 0. While nearly 87% of these households lack electricity altogether, the remaining 13% have access with attributes below the minimum thresholds for capacity and duration that characterize tier 1. Accordingly, while the data used in this analysis are from a representative household survey (Luzi *et al.,* 2020), there may be oversampling from among households with the lowest access levels.

Nearly all households lacking access to at least basic electricity (tier 0) are in rural areas, highlighting that geography and remoteness are the primary barriers that explain the lack of electricity in Honduras. Figure 1 also shows that conditional on having access to electricity, Honduran households are most likely to meet the definitions of tier 3 or tier 5 electrification. The density of households across the tiers indicates that the overall quality or functionality of

https://doi.org/10.1017/bca.2024.14 Published online by Cambridge University Press

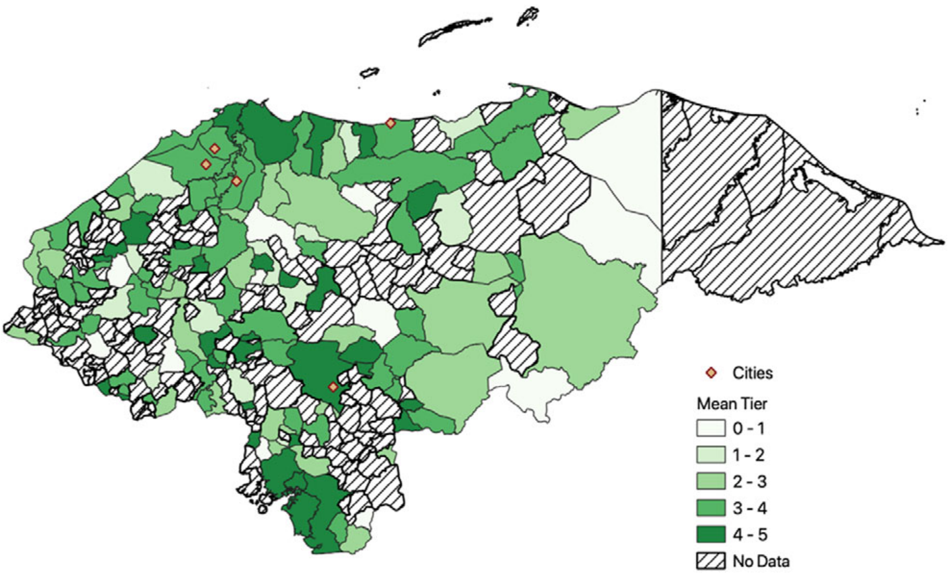

Figure 2. *Honduras municipalities shaded by average electrification tier. Municipalities without MTF survey data are indicated using diagonal lines.*

electrification varies considerably within the country, with some households only having basic access that supports lighting and cell phone charging services, and others benefiting from other services stemming from a range of appliances that more substantially enhance household productivity and time use. Despite the high rates of national electrification in Honduras, only 38% of sample households have tier 5 access, suggesting the potential for large gains to be made in terms of electricity capacity, duration, affordability, and security.

The geography, terrain, and population distribution of Honduras are all closely related to the functionality of electricity access. Figure 2 maps the municipalities of Honduras, which are shaded according to the average household electrification tier as indicated by the MTF survey data (Luzi *et al.,* 2020).[4] Darker shaded municipalities have higher-tier electricity on average. Unsurprisingly, the areas of the country with higher-quality electricity access, as denoted by higher electrification tiers, are located closer to both urban centers and the national grid. As grid-based electricity generally remains the primary means of achieving tier five electrification in Honduras, the map depicts the expected pattern of higher-tier access in more connected, urban areas, and lower-tier access in more remote, rural parts of the country.

Honduras has made significant progress toward improving access to electricity in the last two decades, with access increasing from 70% in 2000 to nearly 92% in 2018 (World Bank *et al.,* 2020). The country has national electrification targets related to electricity coverage as well as targets for renewable generation capacity. Following the SDGs, Honduras has a universal electrification target of 2030 (República de Honduras, 2020).

[4] Municipalities indicated with gray, diagonal lines were not included in the MTF sampling frame. The MTF sampling strategy can be found at https://datacatalog.worldbank.org/dataset/honduras-multi-tier-framework-mtf-survey.

https://doi.org/10.1017/bca.2024.14 Published online by Cambridge University Press

The government plans to achieve this goal through a combination of grid expansion and off-grid solutions (Government of Honduras, 2010; República de Honduras, 2020). The government has also set a renewables generation target of 60% by 2022 and 80% by 2038 (Washburn & Pablo-Romero, 2019). Hydropower and solar energy are the most abundant sources of non-fossil fuel-generated electricity in Honduras today (Flores *et al.,* 2011).

3.2. Electrification trajectories

Given Honduras's continued need to expand basic energy services and improve electricity quality on a number of dimensions (e.g., duration, availability, and reliability), several potential electrification trajectories could be considered to help achieve the national target of universal access. To provide insight into tradeoffs inherent in these potential pathways, this article applies the EAD concept to quantify the dividends lost from slow and incomplete energy transitions (SEforALL *et al.,* 2017; Marzolf *et al.,* 2019).

To establish the benefits forgone over the BAU electrification transition, we first characterize the BAU electrification trajectory in Honduras, both in terms of household electricity access as well as across the MTF electrification tiers. We build population growth and urbanization trends into this baseline.[5] Unfortunately, the MTF and surveys aimed at measuring the distribution of tiers in specific countries are relatively new, and all data available thus far are cross-sectional, which limits our ability to characterize the BAU rate of transitioning across tiers. Further, projections of electrification several decades into the future are highly uncertain. These data limitations and uncertainties motivate our construction of two different BAU baselines, one with a slower progression through the tiers and one with a faster tier progression. For both baselines, we assume that the historical annual electrification rate realized over the period 2012–2018 is maintained – an increase of 3.3 percentage points per year in rural areas and 0.25 percentage points per year in urban areas. In both baselines, this electrification rate is applied to the tier 0 to tier 1 transition; that is, if 2.35% of urban households are in tier 0 in 2021, only 2.1% of those remain in tier 0 in 2022.[6]

For the slower tier progression baseline (Figure 3A), we allocate newly electrified households into the MTF tier proportions. For example, if 45% of the urban population had tier 5 electrification, then 45% of the electrification increase between 2021 and 2022 would be transferred into tier 5 electrification. Under this baseline, Honduras reaches universal urban and rural electrification in 2026. Following universal electrification, this baseline assumes that households maintain their tier position.

For the more rapid tier progression baseline (Figure 3B), we maintain the MTF tier distribution for tiers 1–4 but then assume that tier 5 electrification increases according to the overall rate of electrification (1.59 percentage points annually). For example, if 45% of households had tier 5 electrification initially, 46.59% of households are placed in tier 5 in the second year of our EAD calculation. Tiers 1–4 are distributed according to the process described for the slower tier progression baseline. For example, if 22% of households in tiers

[5] We use an urban population growth rate of 2.9% and a rural population growth rate of 0.27%, which are based on average population growth rates in Honduras between 2012 and 2019 (World Bank, 2021).

[6] We use the tier distribution available from the 2017 MTF survey but conduct the EAD calculation starting in 2021.

https://doi.org/10.1017/bca.2024.14 Published online by Cambridge University Press

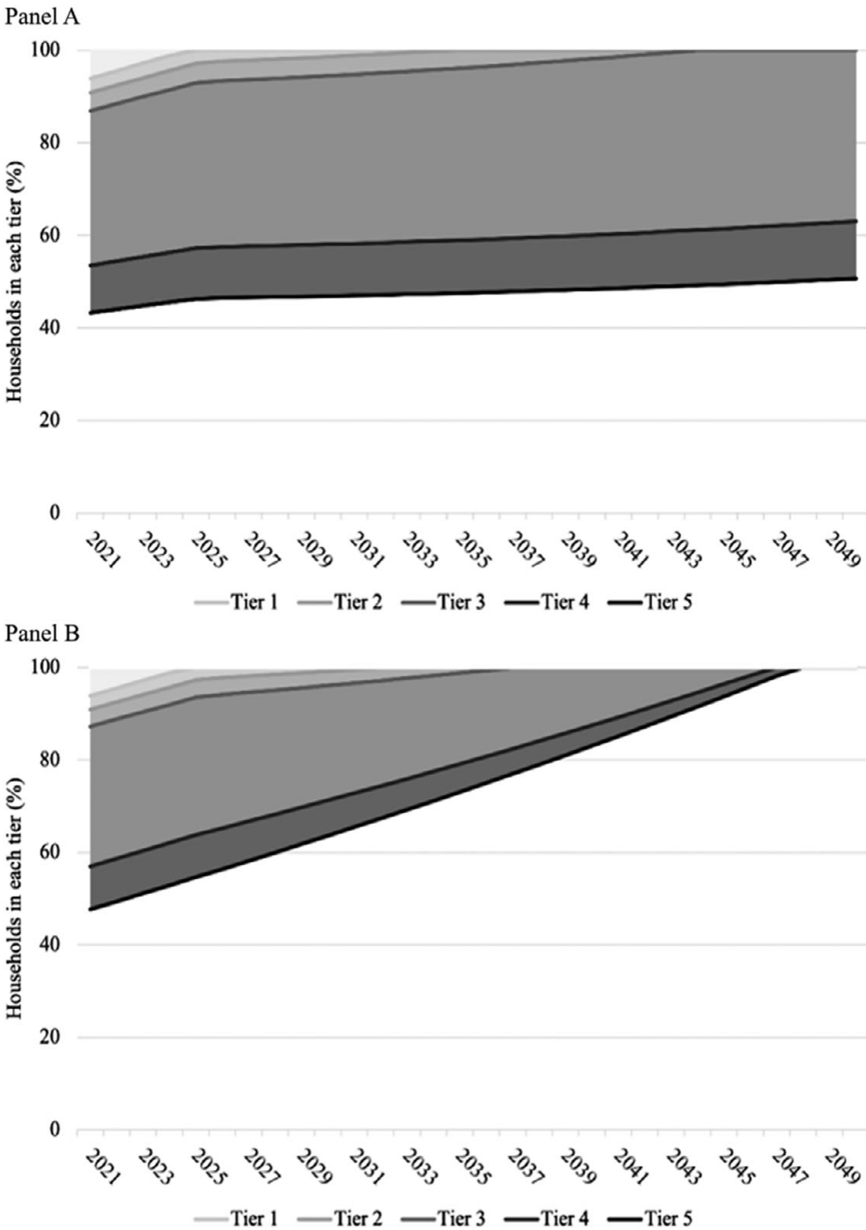

Figure 3 *Distribution of households across tiers for baseline 1, which represents a slower transition through the tiers (Panel A), and baseline 2, which represents a faster transitions through the tiers (Panel B).*

1–4 were initially in tier 4, then 22% of households remaining in tiers 1–4 in 2022 continue to be in tier 4. Because the share of households in tier 5 is increasing over time in this second baseline, the share remaining in tiers 1–4 continues to diminish even after universal basic electrification is achieved in 2026.

https://doi.org/10.1017/bca.2024.14 Published online by Cambridge University Press

3.3. Scenarios characterization

The next step in calculating the EAD is to consider alternative scenarios of intervention to accelerate electrification above what is achieved in the BAU electrification baseline. We consider three alternative scenarios for our analysis. First, we consider a universal tier 5 electrification scenario (hereafter referred to as Tier 5 EAD), which corresponds with policies such as universal, high-quality grid or mini-grid coverage or expansion of high-capacity generators or stand-alone systems with storage. In this analysis, rather than working through the tiers as described in the baseline characterizations, all households are assumed to gain access to tier 5 electrification in year one and to maintain this access thereafter. Second, we examine a universal tier 3 electrification scenario (hereafter referred to as Tier 3 EAD), which corresponds with policies such as an expansion of unreliable grid access or high-end solar home systems and solar mini-grids without robust storage or generator back-up. For this scenario, only benefits obtained through tier 3 electrification of households with less than that level of initial access are considered in the EAD calculation; the EAD is not changed by movement in tiers 4 and 5. Third, we examine a hybrid scenario of universal urban tier 5 electrification and universal rural tier 3 electrification (hereafter referred to as Hybrid EAD). Finally, for the purposes of comparison, we calculate the EAD using a binary definition of electrification (hereafter referred to as Electrified EAD).

Existing energy policy in Honduras informed development of the electrification scenarios. The national government recently approved a $177 million investment project in the national grid (BN Americas, 2019), demonstrating a commitment to grid investments. Despite grid investment priorities, off-grid solutions remain a potentially important component of Honduras' electrification transition, especially given the costs associated with reaching the remote and sparsely populated communities currently lacking grid access. While the penetration of distributed hydropower and solar technologies – like mini-grids and solar home systems – is currently very low, they could be scaled-up to contribute to the Tier 3 electrification scenario in the future. Our hybrid scenario combines these two possibilities. While grid improvements may be a priority, given physical limitations to infrastructure development, grid-based electricity access will be slower in rural areas compared to urban areas. Thus, the hybrid scenario incorporates the realities of these geographical differences into the EAD calculation.

3.4. Benefits valuation

We take a social net benefit perspective to inform the inclusion of the set of benefits modeled in our estimation of the EAD for Honduras, including benefits accruing to connected households as well as those from positive spillovers to society (e.g., climate mitigation). We discuss the valuation of benefits associated with electricity use for lighting ($B^{L}_{t_0,t_1,y,g}$) and phone charging ($B^{PC}_{t_0,t_1,y,g}$); reduced emissions ($B^{CO_2}_{t_0,t_1,y,g}$); changing study time allocations for children by gender (GS and BS for girls and boys, respectively) ($B^{GS}_{t_0,t_1,y,g} + B^{BS}_{t_0,t_1,y,g}$); ownership of electric assets including radios, fans, televisions, and refrigerators ($\sum_{\forall a \in A} B^{a}_{t_0,t_1,y,g}$); and reductions in business expenses due to unreliable electricity access ($B^{R}_{t_0,t_1,y,g}$). The aggregation of benefits is calculated as

$$B_{t_0,t_1,y,g} = B^{L}_{t_0,t_1,y,g} + B^{PC}_{t_0,t_1,y,g} + B^{CO_2}_{t_0,t_1,y,g} + B^{GS}_{t_0,t_1,y,g} + B^{BS}_{t_0,t_1,y,g} + \sum\nolimits_{\forall a \in A} B^{a}_{t_0,t_1,y,g} + B^{R}_{t_0,t_1,y,g}. \tag{3}$$

The benefits specified in Equation (3) were selected based on two main considerations: (i) evidence from the empirical literature on the impacts of electrification, and (ii) data that was available for the Honduran context. For example, regarding the former, in their systematic review, Jeuland *et al.* (2021) identify lighting, appliances, cooling, and household income generation as key energy services providing benefits to households, leading to the investigation of benefits related to lighting, asset ownership (including for cooling), and reduced business expenses.[7] Other studies find evidence of electricity access returns to children's study time (Daka & Ballet, 2011; Khandker *et al.,* 2012; Khandker *et al.,* 2013, 2014; Samad *et al.*, 2013; SEforALL, 2017; Van de Walle *et al.,* 2017; Litzow *et al.,* 2019) and in the form of emissions reductions (Jeuland *et al.,* 2020, 2021). The benefits included in our calculations should not be taken as exhaustive of all of the economic benefits of electrification to households; for example, benefits such as health improvements and new income generation opportunities may be appropriate to include in an EAD calculation, depending on the geographical context and data availability. Additionally, in this article, we focus exclusively on households and do not consider the benefits that might come with better, more reliable electricity access for commercial and industrial consumers.

Each benefit is first quantified in its relevant units and then valued in monetary terms (Peterson, 2003; Boardman *et al.*, 2018; Whittington & Cook, 2019). Lighting benefits ($B^{L}_{y,t_0,t_1,g}$) are calculated using the concept of avoided coping costs (Pattanayak *et al.,* 2005), as the reduced expenditures on kerosene, the most common non-electric lighting fuel in Honduras (Luzi *et al.,* 2020):

$$B^{L}_{t_0,t_1,y,g} = E^{K}_{t_0,t_1,y,g}. \tag{4A}$$

Similarly, mobile phone charging benefits are calculated as reduced expenditures on mobile phone charging outside the home:

$$B^{PC}_{t_0,t_1,y,g} = E^{PC}_{t_0,t_1,y,g}. \tag{4B}$$

Emissions benefits are measured according to reduced demand for more highly polluting lighting fuels. Reduced carbon dioxide (CO_2) benefits are calculated as:

$$B^{CO_2}_{t_0,t_1,y,g} = (Q^{K}_{t_0,t_1,y,g} \cdot \sum\nolimits_{\forall p \in P} Em^{K}_{P}) \cdot B^{CO_2} \tag{4C}$$

where $Q^{K}_{t_0,t_1,y}$ is the reduction in quantity of kerosene used and B^{CO_2} is the social cost of carbon. $\sum_{\forall p \in P} Em^{K}_{P}$ is the CO_2 equivalent of reduced emissions for pollutants in kerosene including methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), organic carbon (OC), and black carbon (BC), in addition to direct CO_2. We convert all of these avoided emissions into their CO_2 equivalents to conduct the valuation according to Equation (4C) using the method described in Jeuland *et al.* (2018), previously used to value the benefits of

[7] Jeuland *et al.* (2021) also identify cooking, heating, industrial energy generation, and agriculture as energy services. We do not include these in the EAD for Honduras as they are not contextually relevant (only 15% of the household sample reports ever using electricity for cooking and less than 0.3% of the household sample reports heating their home (Luzi *et al.,* 2020)) or the microdata do not fully characterize these benefits (as is the case for industrial electricity use and electricity use in agriculture).

use of cleaner-burning cooking technologies and fuels. While we follow the convention in the literature by valuing emissions benefits using the social cost of carbon (Watkiss & Hope, 2011), we recognize that this parameter does not comprehensively include all damages, ignores equity issues including heterogeneity between and within countries, and is sensitive to discounting and assumed growth patterns, among other challenges (Kornek *et al.,* 2021). Nevertheless, the social cost of carbon is the most widely used metric for full social costing of emissions, and it allows for the transparent inclusion of climate benefits in the EAD framework. Future work could examine sensitivity of the EAD estimates to the value that is given to reduced emissions.

We calculate the benefits of children's study time for girls and boys ($\rho = \{G,B\}$) using the relationship between study time and educational attainment and the concept of wage returns to education (Psacharopoulos & Patrinos, 2018; Patrinos & Psacharopoulos, 2020). We first calculate the percent change in secondary school completion associated with the increase in study time at higher electrification tiers ($\Delta\rho SSC_{t_0,t_1,y}$). Next, we value this change using the estimated annual wage return to secondary education for a given geography (WR_g):

$$B^{\rho S}_{t_0,t_1,y,g} = \Delta\rho SSC_{t_0,t_1,y} \cdot WR_g. \tag{4D}$$

We parameterize these benefits using regional estimates for wage returns to education (Psacharopoulos & Patrinos, 2018; Patrinos & Psacharopoulos, 2020) and for the relationship between study time and educational attainment (Llach *et al.,* 2009; Holland *et al.,* 2015). Though the literature identifying these causal linkages is limited and additional empirical evidence would strengthen this valuation approach, using wage returns is a conservative approach to valuing educational benefits, given the myriad private and social benefits of education.

We next calculate benefits associated with asset ownership as the product of the change in asset ownership associated with higher electrification tiers ($\Delta a_{t_0,t_1,y,g}$) and the consumer surplus of that asset (CS^a), derived following Boardman *et al.* (2018) based on purchase prices and average quantities owned for basic appliances of the types. Specifically, assuming a linear demand curve and using price elasticity estimates found in the literature for each asset (Bush, 2002; Rapson, 2014) we can estimate the demand curve; the area under these demand curves provides an estimate for the consumer surplus associated with asset ownership (see Supplementary Figure B1). This is calculated for all assets $a \in A$, which includes fans, radios, televisions, and refrigerators:

$$B^{a}_{t_0,t_1,y,g} = \Delta a_{t_0,t_1,y,g} \cdot CS^a. \tag{4E}$$

Finally, we calculate the benefits of improved reliability according to Equation (4F)) using the coping costs concept, as the reduction in business expenditures incurred from a lack of reliable electricity ($\Delta BE_{t_0,t_1,y,g}$):

$$B^{R}_{t_0,t_1,y,g} = \Delta BE_{t_0,t_1,y,g}. \tag{4F}$$

We incorporate this reduction in business expenditures associated with limited reliability as a proxy for the benefits provided by the possibility of small, home-based businesses that require reliable electrification available at higher electricity access tiers.

3.5. Benefits valuation for consumer surplus approach

For simplicity, and due to limited evidence for parameterization in the existing literature, we calculate the same consumer surplus (or use the same demand curve) across all geographies. We calculate consumer surplus following Boardman *et al.* (2018) and assuming a demand curve with constant elasticity. We set the elasticity using the average, long-term price elasticity for electricity estimated by Labandeira *et al.* (2017) of −0.524. Using this elasticity, we calculate the area under the demand curve between average electricity quantities demanded across tiers.[8] To calculate the consumer surplus, we then subtract electricity expenditures, which we operationalize as the average electricity tariff in Honduras.[9] We consider $SB_{t_0,t_1,y,g}$ to be the emissions benefits of moving across electricity tiers (i.e., $SB_{t_0,t_1,y,g} = B^{CO_2}_{t_0,t_1,y,g}$) and calculate this benefit as described in Equation (4C).

4. Data and model parameterization

The main data for model parameterization come from the 2017 MTF survey for Honduras (Luzi *et al.,* 2020). This cross-sectional household survey contains information about dimensions of household energy access across a variety of sources including grid, mini-grid, generators, solar home systems, and rechargeable batteries. It also covers non-electricity energy sources including firewood, kerosene, and LPG. These metrics allow for household electrification tier classification according to the MTF framework. In addition, the data contain detailed household information on asset ownership, expenditures, cooking technology, economic activity, and time use. Despite this strength, the household survey data are cross-sectional and disallow for the estimation of causal relationships between electricity access tier and estimated benefits, a shortcoming of the data. We also draw on information available from published reports and journal articles to further parametrize the model.

Four methods were used to parameterize the model – literature review, descriptive statistics, regression-based data analysis, and consumer surplus calculations. We briefly discuss each method in turn and summarize all parameters in Table 2. Table 2 reports all parameters used to estimate the EAD along with summarizing information including ranges, relevant tiers, methods, data, and study characteristics as relevant. Based on the model parameterization, we establish qualitative categories of benefits by tier for Honduras (Supplementary Table A1). Further, while our primary EAD calculations include tier-based benefits, we provide a comparison to the non-tier based Electrified EAD; parameters for this estimation are included in Supplementary Table A2.

[8] Because the constant elasticity assumption leads to implausible behavior at low and high quantities of consumption, we assume a horizontal demand curve for the movement from tier 0 to tier 1 and calculate consumer surplus as the area between tier 0 and tier 1 demand, multiplied by the choke price (19.7 Lempira/kWh (Luzi *et al.,* 2020)). We subtract electricity expenditures at current prices at the quantity demanded in tier 1 to obtain the final consumer surplus estimate.

[9] In theory, to calculate the true social surplus (and not simply consumer surplus), one would also need to account for the full costs of electricity supply rather than the average tariff alone (since electricity service may be partially subsidized). Due to lack of data on these full costs, our estimates do not account for the cost of such subsidies, if they exist.

Table 2. *Model parameters*

Parameter description	Units	Range	Value used U	Value used R	Tier U	Tier R	Method	Data Source	Context
Kerosene price	L/l	18.6–26.2	22.4		1		Literature review	OLANDE and IDB (2020)	Honduras, 2014–2018
Change in kerosene	l/year		−5.5	−16.4	1	1	Estimated by regression	Luzi *et al.* (2020)	Honduras, 2017
Change in cell phone charging	L/month		−14.58 ‖ 0	−15.65 ‖ −8.38	1 ‖ 2	1 ‖ 2	Estimated by regression	Luzi *et al.* (2020)	Honduras, 2017
CO_2 in kerosene	g/MJ	140.4–162	151.4		1	1	Literature review	Jeuland *et al.* (2018)	
Black carbon in kerosene	g/MJ	0.007–0.02	0.012		1	1	Literature review	Jeuland *et al.* (2018)	
CH_4 in kerosene	g/MJ	0.001–0.05	0.017		1	1	Literature review	Jeuland *et al.* (2018)	
N_2O in kerosene	g/MJ	0.03–0.08	0.055		1	1	Literature review	Jeuland *et al.* (2018)	
CO in kerosene	g/MJ	0.4–3.1	1.177		1	1	Literature review	Jeuland *et al.* (2018)	
OC in kerosene	g/MJ	0.003–0.01	0.0057		1	1	Literature review	Jeuland *et al.* (2018)	
GWP CO_2	g CO_2 equivalent/MJ		1		1	1	Literature review	Jeuland *et al.* (2018)	
GWP black carbon	g CO_2 equivalent/MJ	2003.2–5644.9	2886.6		1	1	Literature review	Jeuland *et al.* (2018)	
GWP CH_4	g CO_2 equivalent/MJ	62.4–105.1	77.5		1	1	Literature review	Jeuland *et al.* (2018)	
GWP N_2O	g CO_2 equivalent/MJ	249.9–267.3	263.0		1	1	Literature review	Jeuland *et al.* (2018)	
GWP CO	g CO_2 equivalent/MJ	11.8–20.7	16.1		1	1	Literature review	Jeuland *et al.* (2018)	
GWP OC	g CO_2 equivalent/MJ	−778.3–−276.2	−397.9		1	1	Literature review	Jeuland *et al.* (2018)	
Fuel energy density	MJ/kg		45		1	1	Literature review	Jeuland *et al.* (2018)	

Table 2. *Continued*

Parameter description	Units	Range	Value used U	Value used R	Tier U	Tier R	Method	Data Source	Context
Fuel efficiency	Percent	0.44–0.5	0.47		1	1	Literature review	Jeuland *et al.* (2018)	
Social cost of carbon	L/g CO_2	0.0002–0.002	0.0007		1	1	Literature review	Nordhaus (2017)	
Change in study time (girls)	minutes/day		53.97‖ 30.86		2‖5		Estimated by regression	Luzi *et al.* (2020)	Honduras, 2017
Change in study time (boys)	minutes/day		19.57		3		Estimated by regression	Luzi *et al.* (2020)	Honduras, 2017
Minimum wage	L/hour	22–37	32	24	2‖3‖5		Literature review	WageIndicator (2021)	Honduras, 2021
Change in secondary school attainment (girls)			4.72%‖ 2.70%		2‖5		Literature review	Llach *et al.* (2009)	Argentina, 2006–07
Change in secondary school attainment (boys)			1.71%		3		Literature review	Llach *et al.* (2009)	Argentina, 2006–07
Return to secondary education	L/year		7321.6	5491.2	2‖3‖5		Literature review	Psacharopoulos and Patrinos (2018); Patrinos and Psacharopoulos (2020)	Global; Latin America and the Caribbean 1950–2014
Change in radio ownership	Radios		0.29		1		Estimated by regression	Luzi *et al.* (2020)	Honduras, 2017

https://doi.org/10.1017/bca.2024.14 Published online by Cambridge University Press

Table 2. *Continued*

Parameter description	Units	Range	Value used U	Value used R	Tier U	Tier R	Method	Data Source	Context
Radio consumer surplus	L/year		24.07		1		Calculation from Boardman *et al.* (2018)	Bush (2002); World Bank (2010)	United States, 2001; Panama, 2008
Change in fan ownership	Fans		0.76	0.36	2	2	Estimated by regression	Luzi *et al.* (2020)	Honduras, 2017
Fan consumer surplus	L/year		310.95		2	2	Calculation from Boardman *et al.* (2018)	World Bank (2010); Rapson (2014)	United States, 1990–2005; Panama, 2008
Change in TV ownership	TVs		0.68‖0.53‖ 0.31‖0.04	0.68‖0.02	2‖3‖4‖5	2‖4	Estimated by regression	Luzi *et al.* (2020)	Honduras, 2017
TV consumer surplus	L/year		289.20		2‖3‖5	2‖4	Calculation from Boardman *et al.* (2018)	Bush (2002); World Bank (2010)	United States, 2001; Panama, 2008
Change in refrigerator ownership	Refrigerators		0.25‖0.37	0.25‖0.37	2‖3	2‖3	Estimated by regression	Luzi *et al.* (2020)	Honduras, 2017
Refrigerator consumer surplus	L/year		1088.90		2‖3	2‖3	Calculation from Boardman *et al.* (2018)	Dale (2008); World Bank (2010)	United States, 1980–2002; Panama, 2008
Household size	per household	1–20	4.3	4.7			Descriptive statistics	Luzi *et al.* (2020)	Honduras, 2017

Table 2. *Continued*

Parameter description	Units	Range	Value used U	Value used R	Tier U	Tier R	Method	Data Source	Context
Number girl children	per household	0–6	0.63	0.82			Descriptive statistics	Luzi *et al.* (2020)	Honduras, 2017
Number boy children	per household	0–7	0.67	0.88			Descriptive statistics	Luzi *et al.* (2020)	Honduras, 2017
Change in business expenditures	L/month		−93.48	−93.48	4	4	Estimated by regression	Luzi *et al.* (2020)	Honduras, 2017
Electricity consumption	kWh/month		0 ‖ 36.2 ‖ 55.3 ‖ 84.7 ‖ 100.2 ‖ 117.9		0 ‖ 1 ‖ 2 ‖ 3 ‖ 4 ‖ 5		Descriptive statistics	Luzi *et al.* (2020)	Honduras, 2017
Electricity price	L/kWh		3.12				Descriptive statistics	Luzi *et al.* (2020)	Honduras, 2017
Energy price elasticity			−0.524				Literature review	Labandeira *et al.* (2017)	Global, 1970–2017
Exchange rate	L to US$		23 L to 1 US$				Literature review	Oanda	Honduras, 2021
Discount rate		3–12%	5%				Literature review	OMB, 2003; IADB, 2021	

Note: Minimum wage values are assigned as midpoints of agricultural minimum wages (rural) and non-agricultural minimum wages (urban). Parameters used for the Electrified EAD calculation that differ from those in this table are available in Supplementary Table A2.

4.1. Literature review

We rely on the existing literature to parameterize market values, environmental impacts, educational returns, and discount rates used in the EAD calculation for Honduras. Market values include the kerosene price and minimum wage in Honduras as well as the Lempira (L)-USD exchange rate. Environmental impacts include the pollution content of kerosene for a variety of pollutants including carbon dioxide (CO_2), black carbon, methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), and organic carbon (OC) as well as the global warming potential of each pollutant converted into CO_2 equivalents using the method outlined in Jeuland *et al.* (2018). We use estimates for the wage returns to education (Psacharopoulos & Patrinos, 2018; Patrinos & Psacharopoulos, 2020) and the relationship between study time and secondary school attainment (Llach *et al.,* 2009) to value educational benefits. Finally, we use a discount rate of 5% in our calculations.

4.2. Descriptive statistics

As a representative household survey, the MTF data provides insight into household composition used in this analysis. We use average household size, average number of girl children, and average number of boy children from the survey to characterize household composition for the EAD calculations. We use average monthly electricity consumption by tier and the average electricity price for the benefits valuation that takes a consumer surplus approach.

4.3. Regression

We use regression analysis to evaluate changes in key electrification-related outcomes across access tiers to parameterize changes in kerosene use, cell phone charging behavior, study time, ownership of electric appliances, and business expenses due to unreliable electricity access. Specifically, we estimate the following equation:

$$Y_i = \alpha + \beta_1 T_i + \beta_2 U_i + \beta_3 T_i \times U_i + \rho X_i + \varepsilon_i, \tag{5}$$

where Y_i refers to the outcome of interest (see Table 2 for a complete list); T_i is an indicator variable that takes a value of 1 for households in the highest tier of consideration; U_i is an indicator variable that takes a value of 1 for households living in urban areas; and X_i is a vector of household controls including the gender and age of the household head, household size, number of children, annual income, and an asset index calculated based on household ownership of transportation vehicles, home ownership, roof construction type, and ownership of improved sanitation and water filtration technologies. Standard errors are clustered at the municipality level, and all regressions are probability-weighted based on the survey sampling frame. For the multi-tier analysis, we run Equation (5) on sets of households from contiguous tiers (i.e., for households in tiers 0 and 1, 1 and 2, 2 and 3, 3 and 4, and 4 and 5) to assess how outcomes vary across households in these respective tiers. For the binary electrification analysis, we run Equation (5) collapsing all tiers into one binary indicator that takes a value of 1 for households with electricity access. Due to sample size limitations, we analyze the change in business expenses across the entire population rather than separating the impacts on the urban and rural populations (i.e., we remove $T_i \times U_i$ from the estimating equation,

https://doi.org/10.1017/bca.2024.14 Published online by Cambridge University Press

Equation (5)). We take this tier-based approach to the regression estimation to allow for flexibility in determining where the benefits of electrification manifest and to allow subsequent matching of those benefits to the relevant electrification strategies for a particular context (e.g., in Honduras, moving to full tier 5 electrification, or a mixed tier 3 (rural) and tier 5 (urban) approach).

From the regression results, we use a threshold of $p < 0.10$ to determine the inclusion of benefits associated with an increase to a higher energy access tier. We value these benefits using the estimated coefficients (i.e., β_1 for rural households and $\beta_1 + \beta_3$ for urban households). Full regression results are reported in Supplementary Table A3. There are three instances in which the estimated coefficients go in the opposite direction from what we would expect, that is, the estimates suggest that a higher tier of electrification reduces some outcome.[10] This could reflect nonlinearities in the benefits derived from electrification; for example, it is plausible that moving into a higher tier of electrification could, in some cases, generate contemporaneous changes at the household level that lead to conflicting impacts. For example, improved electricity access could allow for home business production as an income-generating activity, which may also shift children's time use toward income generation and away from study time. Alternatively, this could reflect econometric challenges arising from our use of cross-sectional data, specifically, bias (arising from endogeneity or omitted variables) or lack of statistical power to detect true impacts. In each of the instances in which coefficients have the unexpected sign, aggregating over the prior or subsequent tier transitions leads to more intuitive results. Accordingly, in such cases, we assign the aggregated (positive) effect to the tier transition with the intuitive effect size, and set the corresponding benefit from the other transition to zero.

As this article applies a rather simple regression approach to parameterization using the MTF data, the magnitude and precision of our estimates could be biased, as discussed above. Ideally, an EAD analysis would incorporate more rigorous evaluation and estimation strategies to better identify such impacts from improvements in the quality of electricity access, such as a quasi-experimental or randomized design (Angrist & Pischke, 2009; Ozturk, 2010; Bos *et al.,* 2018; Stern *et al.,* 2019; Bayer *et al.,* 2020; Jeuland *et al.,* 2021). Given the nature of the MTF data and the lack of data alternatives, such an approach is not possible in our initial demonstration of the EAD concept and framework. Despite this limitation, we believe that the demonstration of the framework remains valuable, and urge researchers to better isolate the causal impacts of tiered improvements in future work, to further develop the basic modeling approach.

4.4. Consumer surplus from asset ownership calculations

Following Boardman *et al.* (2018), we calculate the consumer surplus of appliance ownership assuming a linear demand curve and using price elasticity estimates found in the

[10] Unexpected signs are observed for the following transitions: (i) cell phone charging expenditures outside the home for urban households transitioning from tier 1 to tier 2; (ii) boys study time for urban households transitioning from tier 1 to tier 2; and (iii) television ownership for rural households transitioning from tier 4 to tier 5.

https://doi.org/10.1017/bca.2024.14 Published online by Cambridge University Press

literature for each asset (Bush, 2002; Rapson, 2014). In this calculation, we first calculate the underlying demand curve for each appliance using the price and quantity of each appliance owned. In the absence of population-level appliance price and quantity information from Honduras, we use data from Panama, a regional neighbor (World Bank, 2010). Using the derived demand curves, we estimate consumer surplus as the area between this demand curve and the appliance price for one owned appliance. As this consumer surplus represents an aggregate amount across the appliances' lifespans, we calculate annual household consumer surplus as the aggregate consumer surplus multiplied by a capital recovery factor calculated for each appliance.[11] The capital recovery factor calculation assumes a discount rate of 10% and appliance lifespans of 10, 5, 10, and 11 years for radios, fans, televisions, and refrigerators, respectively. These lifespans are also calculated from the averages in the sample (World Bank, 2010). We use these annual household-level consumer surplus estimates to value increases in appliance ownership assessed using the regression model estimating using the MTF data, as specified in Equation (5).

4.5. Comparisons with electrification benefits in the empirical literature

The existing empirical literature offers evidence on the value of different benefits of electrification in low- and middle-income countries. While direct comparisons of benefits estimates within the existing literature may be incomplete – estimates may differ, especially, due to the tiered approach to estimating benefits of enhanced electrification for the EAD compared to the binary electrification access that dominates the literature – they offer helpful benchmarks for interpreting our model parameterization and subsequent EAD estimates (as presented in Section 5).

Empirical studies suggest that basic electrification – that which might equate to a tier 1 or tier 2 level in the MTF framework – generates benefits related to lighting, emissions, phone charging, and basic appliance use and ownership. Evaluations of the benefits of solar home systems, for example, show that electrified households spend less on cooking and lighting fuels (Beyene *et al.,* 2024) and have higher rates of ownership of low-intensity electric appliances such as radios, televisions, and fans (Diallo & Moussa, 2020). Similarly, Blimpo and Cosgrove-Davies (2019) find lighting and cell phone charging benefits for households in Sub-Saharan African with basic electricity access. Our analysis using MTF data in Honduras reveals tier one benefits of lighting fuel expenditures (and associated emissions reductions) and radio ownership; tier one and tier two benefits of phone charging; and tier two benefits of asset ownership (fan, TV, and refrigerator). In general, these benefits of basic electrification align with findings from the empirical literature; one noteworthy exception is the appearance of benefits of increased refrigerator ownership among households with tier two access – in other contexts, the benefits of refrigeration were only realized once households had enhanced electricity access (Dhanaraj et al., 2018; Blimpo & Cosgrove-Davies, 2019; Dang & La, 2019).

---

[11] We calculate the capital recovery factor (CRF) as

$$\mathrm{CRF} = \frac{r(1+r)^n}{(1+r)^n - 1},$$

where r is the discount rate and n is the appliance lifespan.

https://doi.org/10.1017/bca.2024.14 Published online by Cambridge University Press

The empirical literature also suggests educational returns to electrification, measured as increased study time and educational attainment. Educational benefits are observed from different levels of electricity access. For example, Samad *et al.* (2013), Diallo and Moussa (2020), and Beyene *et al.* (2024) find educational returns to solar home systems in Bangladesh, Côte d'Ivoire, and Ethiopia, respectively, suggesting benefits at low or mid-tier electrification. Peters and Sievert (2016), however, find that access to solar home systems shifts study time from before to after nightfall in several Sub-Saharan African countries, demonstrating more limited educational returns to low-tier access. Evaluations of the educational returns to grid access – representing higher-tier electrification – suggest that children in grid-connected households have higher levels of education (Khandker *et al.,* 2012, 2013; Litzow *et al.,* 2019). In our analysis using the MTF data from Honduras, we find increased study time associated with tier 2, tier 3, and tier 5 electrification. These benefits, and their locations in the tier distribution, align with findings from the empirical literature that both basic and enhanced electrification can promote increased study time and educational attainment.

Finally, several studies examine the productive and income-related benefits of electrification. Studies of lower-tier technologies such as solar home systems find no evidence of impacts on household income (Peters & Sievert, 2016; Beyene *et al.,* 2024). On the other hand, studies of expanded grid access suggest productive uses of electricity and returns to income. Dang and La (2019) find that a 1% improvement in electricity grid quality increases farm production investments by 3.5% in Vietnam, and Samad and Zhang (2016) show that reliable power supply access increases incomes by 17% in India. Further, Alberini *et al.* (2020) find that households in Nepal are willing to pay $1.11 per month for reduced outages, suggesting a household benefit associated with increased reliability. While none of these studies directly measure the business expenses associated with low electricity reliability (the parameter we estimate for our EAD calculations), taken together, they provide evidence that enhanced electrification is needed to achieve productive use benefits. Our analysis using the MTF data for Honduras identifies reduced business expenses associated with power outages among tier four households, which aligns with this evidence from the empirical literature.

5. Results

This section compares the EAD for Honduras across electrification definitions and scenarios. Given the differences in electricity access, rates of electrification, and electricity benefits between rural and urban households, all calculations are shown separately for rural and urban populations. First, we present the EAD calculations at both the household-year and the country-cumulative levels. Second, we decompose the EAD into contributing benefits categories to show how these various benefits accrue to households across electrification scenarios. Finally, we present results using the alternative, consumer surplus calculation approach.

5.1. EAD calculations

We compare the annual, household-level EAD across three tier-based electrification scenarios and one non-tiered comparison electrification scenario. These results are presented in Table 3. Considering first the naïve calculations that ignore a more nuanced definition of

Table 3. *Household annual EAD*

	Electrified EAD		Tier 5 EAD		Tier 3 EAD		Hybrid EAD	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Non–tiered	43.35	51.44						
Tier 0			129.99	105.59	74.11	56.66	129.99	56.66
Tier 1			117.28	79.57	61.40	30.65	117.28	30.65
Tier 2			81.89	59.27	26.01	10.34	81.89	10.34
Tier 3			55.88	48.93	0	0	55.88	0
Tier 4			3.21	0	0	0	3.21	0
Tier 5			0	0	0	0	0	0

Note: Authors' calculations. All values in US$ using exchange rate of 23 L to 1 US$. Columns 1 and 2 do not use MTF tier definitions; rather, estimates are assessed using a binary definition of household electricity access. Columns 3–8 present the EAD for each scenario by tier (the total benefit of moving from the stated tier to the maximum tier reached under the scenario definition).

energy access, we estimate that the annual EAD for an unelectrified urban household in Honduras is approximately $43 per year (Table 3, column 1); for an unelectrified rural household, it is approximately $51 per year (Table 3, column 2). These results – based on a binary definition of electricity access – demonstrate the existence of electrification benefits and suggest that these benefits are larger for rural compared to urban unelectrified households.

Considering next the annual household EAD for tier-based analysis (Table 3, columns 3–8), we find that the non-tiered estimates underestimate the potential benefits of electrification and depict a different pattern of benefits between rural and urban households. Our analysis of the Tier 5 EAD shows that unelectrified, urban households could gain annual benefits amounting to almost $130 from transition to tier 5 electricity access; for rural households, the benefits are valued at approximately $106 per year. These differences are largely driven by higher-value benefits such as increased study time and decreased income loss that accrue only to households reaching the highest tiers of access. Given the small proportion of households realizing these benefits under the current tier distribution, these benefits are not captured in the analysis of increased binary access. There are additional gains to moving into higher-tiered access as well. For example, urban (rural) households with tier 3 access could experience benefits amounting to $56 ($49) per year if they transitioned into tier 5 access (Table 3, columns 3–4). We find similar patterns for Tier 3 and Hybrid EAD estimates, although the magnitudes of benefits are, of course, lower. Comparing the Electrified EAD to our three tier-based scenarios, the estimates for the Electrified EAD are substantially lower. This suggests that the nuanced tier-by-tier parameterization of benefits reveals value from enhanced electrification that a binary approach ignores.

The relative benefits of enhanced electrification depend on the starting point of electrification as well as household economic status. For example, the median annual income among urban households ($4190) is approximately double the median annual income among rural households in our sample ($2101) (Luzi *et al.*, 2020). Thus, the Tier 5 EAD is approximately 3% of annual household income for the median urban household and 5% of annual household income for the median rural household. These relative comparisons

https://doi.org/10.1017/bca.2024.14 Published online by Cambridge University Press

Table 4. *Cumulative EAD*

	Business-as-Usual		Electrified EAD		Tier 5 EAD		Tier 3 EAD		Hybrid EAD	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Non–tiered	0.70	0.76	1.71	15.46						
Baseline 1	1078.6	725.0			797.7	385.5	39.4	59.4	797.7	59.4
Baseline 2	1200.9	732.0			394.7	302.1	20.9	49.4	394.7	49.4

Note: Authors' calculations. All values reported in million US$. Exchange rate of 23 L to 1 US$ was used. A discount rate of 5% was applied to calculate present values. Columns 1 and 2 report the benefits of increasing (un-tiered) electrification across the projected electrification transition of universal electricity access in urban areas by 2028 and in rural areas by 2036. Columns 3 and 4 report the Electrified EAD (binary definition of electrification) for comparison; the time horizon for the Electrified EAD also uses the projected electrification transition of universal electricity access in urban areas by 2028 and in rural areas by 2036. Columns 1–4 do not use the MTF tier definitions. Columns 5–10 report the urban and rural EAD under three development scenarios: Tier 5 in columns 5 and 6; Tier 3 in columns 7 and 8; and a Hybrid in columns 9 and 10. For columns 5–10, the EAD is calculated between 2021 and 2050.

provide the necessary context for building objectives beyond simple economic efficiency, such as equity and fairness, into electrification decisions.

While understanding the annual, household-level EAD calculations provides insight into what shifts between electricity access tiers mean for individual households, cumulative and aggregate EAD calculations are informative for the development of national energy policy. Table 4 presents these cumulative results. To complete our evaluation of the benefits of energy access, we also present the benefits across Honduras' BAU electrification transition. While our main analysis considers the tier-based electrification benefits, we also present untiered BAU and EAD estimations for comparison.

Starting first with the binary, untiered BAU and EAD analysis, we find that universal electrification in Honduras would generate $18.6 million in benefits (Table 4, row 1, sum of columns 1–4). Given Honduras's current electrification trajectory, however, the country will receive less than 8% of these benefits (Table 4, row 1, columns 1–2). The remaining 92% of potential electrification benefits (Table 4, row 1, columns 3–4) will be lost as a result of the time it takes for the country to achieve universal electrification.

Considering next our tiered approach, we calculate the cumulative aggregate (2021–2050) BAU (Table 4, rows 2–3, columns 1–2) and EAD (Table 4, rows 2–3, columns 5–10) across the established electrification scenarios and baselines. While we report results from both Baseline 1 (slower tier progression) and Baseline 2 (faster tier progression), we focus on Baseline 2 results as our main results. As expected, we find that the aggregate EAD is largest for Tier 5 electrification in urban areas – amounting to over $394 million through 2050 (Table 4, row 3, column 5). For rural areas, the Tier 5 EAD is over $302 million (Table 4, row 3, column 6). Taken together, these EAD calculations suggest that incomplete energy transitions in Honduras will leave nearly $697 million in unclaimed energy dividends between 2021 and 2050. Summing the BAU and Tier 5 EAD (Table 4, row 3, columns 1–2 and 5–6), we find that the BAU scenario through 2050 capture just under three-quarters of the aggregate potential energy benefits to Honduras, while slightly over one-quarter of these benefits are lost due to incomplete and delayed energy transitions.

Examining an alternative incomplete energy scenario, we find that failing to achieve universal tier 3 electrification results in an aggregate dividend of over $70 million between 2021 and 2050 (Table 4, row 3, columns 7–8). Approximately 70% of this dividend accrues to rural households, demonstrating how electrification objectives – in terms of quality, reliability, capacity, etc. – affect the distribution of potential benefits across urban and rural populations. Summing the BAU and Tier 3 EAD (Table 4, row 3, columns 1–2 and 7–8) reveals that BAU through 2050 generates approximately 96% of potential electrification benefits, suggesting that immediate attainment of universal tier 3 electrification may not generate substantially more benefits – related to those valued in this analysis – than the country's current timeline. Finally, the Hybrid EAD calculations lie between these two scenarios. Similarly, summing the BAU and Hybrid EAD (Table 4, row 3, columns 1–2 and 9–10) reveals that BAU through 2050 generates just over 81% of potential electrification benefits in Honduras. Figures 4A and 4B depict these cumulative dividends across the 3 electrification scenarios for Baseline 1 (Figure 4A) and Baseline 2 (Figure 4B). Equivalent figures disaggregated by rural and urban populations are available in Supplementary Figure B2. Comparing these results with the BAU benefits and Electrified EAD demonstrates the importance of using a tier-based approach to EAD calculations to evaluate the benefits of various electrification scenarios.

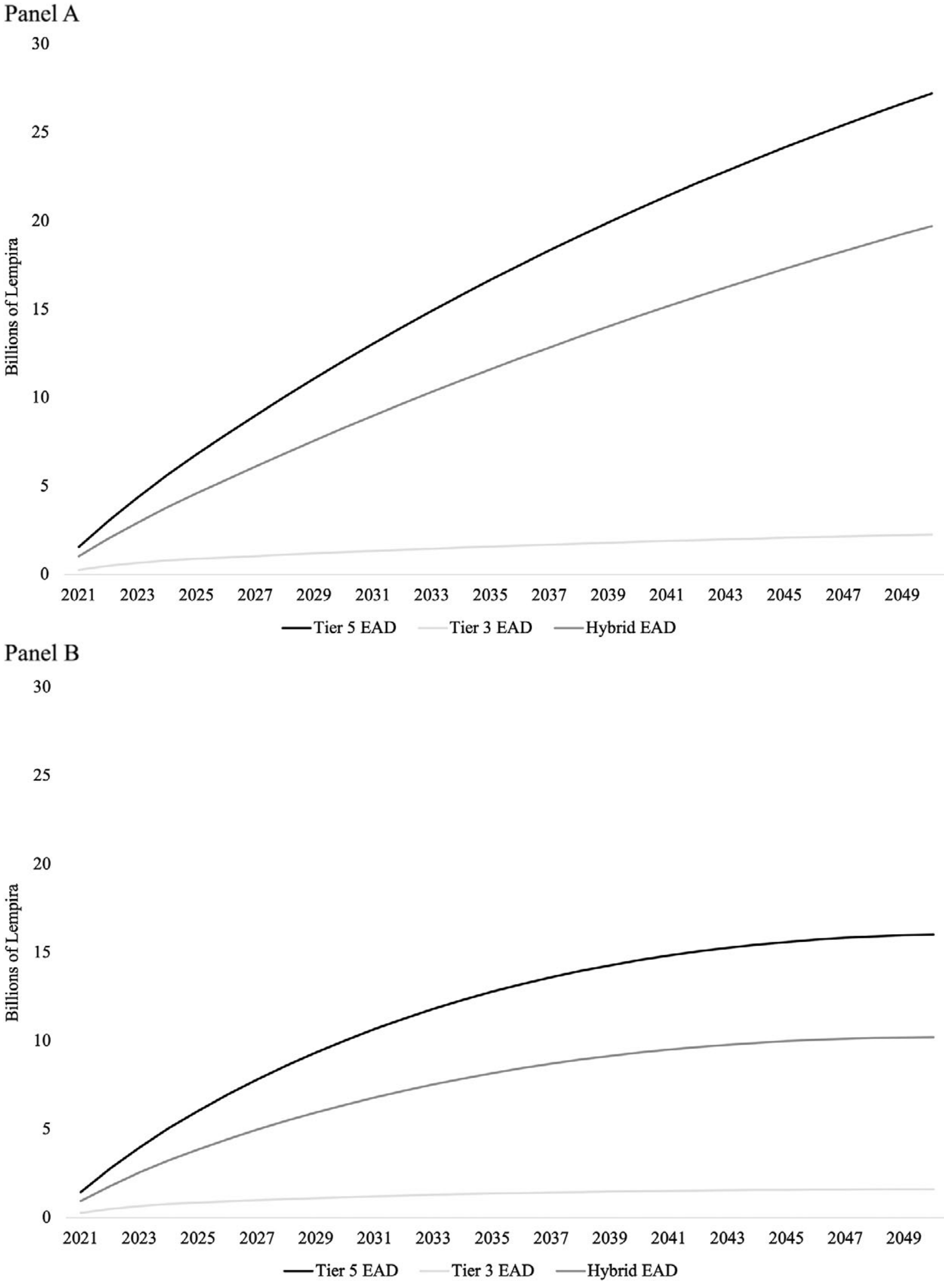

Figure 4. *Cumulative EAD scenario comparison assuming baseline 1 (Panel A) and baseline 2 (Panel B).*

5.2. Contributions across benefits categories

The aggregate EAD calculations demonstrate the significant dividends that are missed through incomplete electrification transitions in Honduras. In Figure 5, we depict the benefit

https://doi.org/10.1017/bca.2024.14 Published online by Cambridge University Press

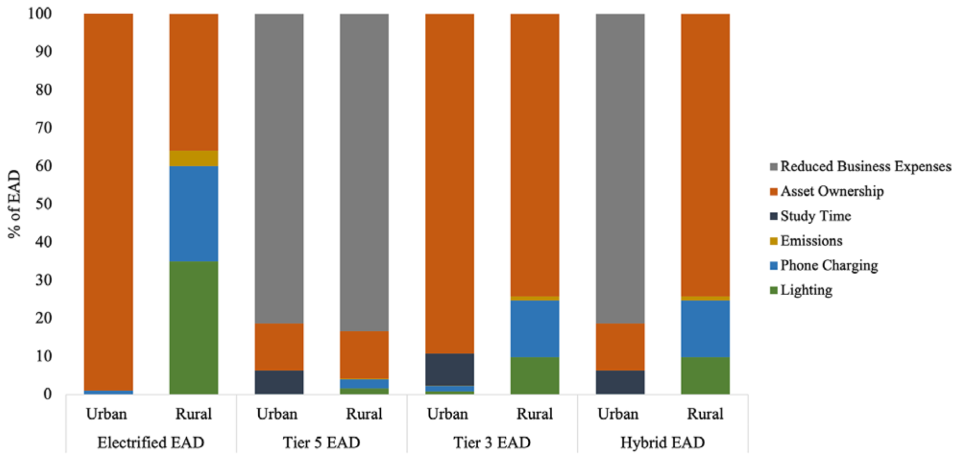

Figure 5. *EAD contributions across benefits categories (baseline 2 shown; proportions across baselines are descriptively identical).*

Table 5. *Consumer surplus-based forgone electricity benefits*

	Tier 5 scenario		Tier 3 scenario		Hybrid scenario	
	(1)	(2)	(3)	(4)	(5)	(6)
	Urban	Rural	Urban	Rural	Urban	Rural
Annual	24.0	101.5	13.1	92.9	24.0	92.9
Baseline 1	377.9	667.3	144.8	542.0	377.9	542.0
Baseline 2	197.4	554.4	82.5	457.4	197.4	457.4

Note: Authors' calculations. All values reported in million US$. Exchange rate of 23 L to 1 US$ was used. A discount rate of 5% was applied to calculate present values. Columns report the urban and rural benefits under three development scenarios: Tier 5 in columns 1 and 2; Tier 3 in columns 3 and 4; and a Hybrid in columns 5 and 6. Rows report different aggregations: Annual benefits in row 1; benefits between 2021 and 2050 assuming baseline 1 in row 2; and benefits between 2021 and 2050 in row 3.

categories that comprise these missed household benefits using Baseline 2 (an equivalent figure using Baseline 1 is available in Supplementary Figure B3). This is important for identifying the relative importance of benefits categories into the overall EAD and can clarify the contributions of benefits that may be challenging to value such as emissions (which relies on estimates of the social cost of carbon) and study time (which relies on wage differentials). Further, it provides flexibility in the presentation of EAD estimates given the possibility of certain benefits being more or less applicable in different contexts. Looking first to our comparison Electrified EAD scenario, we find that 100% of the benefits of electrification for urban households are attributable to asset ownership, which increases with higher-quality electricity access. For rural households, the benefits are distributed across asset ownership, lighting, phone charging, and emissions benefits. Comparing across urban and rural households, categories of potential electrification benefits differ geographically. This is partly due to the differences in starting points in electrification and economic status. The vast majority of urban households are already electrified, such that benefits related to lighting and associated emissions reductions, as well as phone charging would be modest. Accordingly, for urban unelectrified households, it is asset ownership that would especially be enabled. Relatively more rural households are not electrified; thus, low-tier electrification benefits are more significant. Further, the gains from electrification depend on a household's economic starting point – which is higher among urban compared to rural households in our sample. This means there is additional scope for quantifying and monetizing benefits, such as appliance use, among higher-income households that are and will be using more electricity.

Turning to the alternative, tier-based EAD analyses clarifies the importance of other benefit categories. For the Tier 5 EAD calculations, well over 50% of the EAD calculation for both urban and rural households comes from improvements in electricity reliability that decreases businesses expenses that are incurred as a result of blackouts. For both geographies, the second largest benefits share comes from asset ownership. In urban areas, study time makes up the third largest share; in rural areas, phone charging. For the Tier 3 EAD calculations, we find that benefits of asset ownership make up the largest percentage of the EAD for both urban and rural areas. In urban areas, study time and phone charging make up the second largest share; for rural households both phone charging and lighting make up significant shares of the EAD calculation. Finally, the Hybrid EAD reflects both previous scenarios. For urban households, business-related, asset ownership, and study time benefits make up the largest share of the EAD; whereas, for rural households, asset ownership, phone charging, and lighting are the relevant benefits categories. Across all policy scenarios modeled, and in urban and rural locations, we find that changes in emissions represent a small proportion of the overall EAD estimates. These benefits may be more significant (or, alternatively, may become net costs) in other contexts, for example when climate-altering emissions are reduced more substantially due to electrification or if the emissions intensity of electrification technology is high.

5.3. Comparison with consumer surplus from electricity

An alternative approach to estimating the EAD across benefit categories is to estimate the consumer surplus associated with the increased electricity consumption that comes with movements into access to higher electricity tiers. For Honduras, we report the annual and cumulative forgone benefits, calculated as the sum of missed consumer surplus and omitted emission benefits, in Table 5. As with the previous analyses, we focus on Baseline 2 as our primary results.

Across all policy scenarios, we find that the consumer surplus-based estimates show larger forgone benefits for rural households. This differs from our EAD findings of more substantial gains to high tier (tier 5) access among urban households. The EAD approach is more flexible in allowing for differential demands for electricity across tiers and locations, while the consumer surplus approach assumes the same demand curve across tiers and geographies. Nonetheless, it is possible that the EAD may omit important benefits that are not apparent from the disaggregated approach in the MTF analysis.

Another noteworthy difference across approaches is in the magnitudes of the estimates. We find that, for rural households, the consumer surplus approach yields higher estimates of forgone electricity benefits compared to our new EAD approach. This is true for scenarios that transition households into tier 5 and tier 3 electrification. As the consumer surplus approach should encompass all missed benefits of electricity access to a household, these differences in estimates suggest that the EAD approach could be expanded, particularly in rural areas, to consider additional benefits of electrification. We also find that for urban households, scenarios that transition households into tier 5 electrification (Tier 5 Scenario and Hybrid Scenario) yield higher estimates using the EAD compared to consumer surplus approach. As we base our elasticity estimates on the existing demand for electricity throughout Honduras, and urban households in Honduras have the highest baseline access, the urban consumer surplus estimates may underestimate changes in demand that might occur if households had access to high reliability, capacity, and quality connections that are also secure and legal. Given the challenges of estimating changes in electricity demand across uncertain electrification transitions, we argue that the EAD approach offers an alternative framework for estimating the potential gains of faster, more complete energy transitions that are not as dependent on assumptions about electricity demand elasticities, which likely vary across contexts and electricity uses.

6. Policy implications and conclusion

While levels of electricity access in Honduras are high, and the country is on track to achieve universal electrification within the SDG timeline, characterizing this electricity access in terms of reliability, duration, quality, and capacity reveals variation in how households can use electricity and the dividends that result. Our application of the EAD to electrification in Honduras demonstrates the importance of considering these dimensions of energy access – both to characterize electrification in Honduras more fully and also to inform policy. The results of the analysis point to important trade-offs in expanding access to unelectrified households and improving the quality and reliability of electricity to electrified households. For example, while the EAD reveals substantial potential benefits related to electricity use for household business activities, these benefits are only available to households with tier 4 or 5 access. Thus, a strategy to integrate electricity into economic activity more fully would require the expansion of higher quality, more reliable electricity. Further, we find substantial potential gains to tier 3 electrification compared to basic access that supports only low energy uses, but this dividend is concentrated in rural areas. This result is informative, for example, in contextualizing the types of infrastructure needed to realize different electrification benefits. As both grid and non-grid options – such as solar home systems and mini-grids – can provide tier 3 access, our estimates can inform national investments in grid expansion and off-grid technologies, considering the very different costs of such strategies. Overall, our results demonstrate that there are substantial benefits left on the table due to unreliable, insufficient, and poor-quality electricity access.

6.1. Study limitations

The EAD provides a specific framework tool for evaluating these lost dividends of slow or incomplete energy transitions – focusing exclusively on missed household benefits with the intent of informing allocations of energy resources or energy policy design (SEforALL *et al.,* 2017; Marzolf *et al.,* 2019). Yet, there are a number of important limitations of our work. First, the current example of EAD has omitted potential benefits to firms and industry due to data limitations, but future applications could capture electrification benefits beyond those accrued at the household level. Moreover, as the parameterization of the EAD model depends, in our application, on data available in the cross-sectional, 2017 MTF survey for

Honduras, the set of included private benefits is incomplete. For example, additional private benefits such as health returns, investments in electronic assets beyond those identified in our analysis, and potential for new types of income generation could be estimated in contexts in which these benefits are both relevant and where better data exist for their estimation. Relatedly, the EAD model is only as comprehensive as its parameterization. Insofar as the empirical literature is inconclusive regarding the causal relationships between electricity access and various benefits, we must rely on correlational analysis for parameterization. For example, while electrification has been shown to deliver returns in the form of improved education and, by extension, future wages, substantial uncertainty remains in the extent and value of these benefits (Psacharopoulos & Patrinos, 2018; Patrinos & Psacharopoulos, 2020). Accordingly, we must rely on a limited set of estimates on which to base our parameterization. Future iterations of the EAD would benefit from carefully constructed, causal estimates of the short and long-term benefits of electrification and improved valuation of these benefits.

Second, while the EAD estimates benefits missed over an electrification transition, we use cross-sectional data for its estimation. Accordingly, the estimate could miss out on impacts that materialize over time or respond to a changing energy policy landscape. As the EAD is designed as a planning tool, however, these static estimates provide insight into when and how to invest resources into improving electrification. Third, there may exist variation at several different scales in the true benefits of electrification. Dividends may not accrue to everyone in a household equally, and the decision maker may not take such variation into account. For example, if a decision maker in a household chooses to purchase an asset such as a phone, television, or radio, he or she may not account for the costs of that appliance on others in the household – say a case where the technology distracts household children from studying. Without clear guidance from the current literature or from survey data regarding these potential differences we have not incorporated them into our EAD estimate; however, future applications of the framework should do so when context and data availability are amenable to such an approach.

Fourth, the EAD is not set up to provide this direct comparison of costs and benefits. Yet, understanding the costs associated with energy transitions is essential for informing policy. Electricity policy today is largely focused on least-cost electrification models without full consideration of the varied benefits afforded by different electrification tiers and trajectories. Thus, merging the EAD with robust cost analysis would provide the most nuanced insight into the cost-effectiveness of and potential benefits associated with electrification pathways. We include an incomplete, illustrative cost analysis for Honduras in Supplementary Appendix C, yet note that data limitations inhibit fully incorporating this into the EAD framework. Additional cost data is needed – for example, cost information could be obtained from household surveys that indicate expenditures on electricity as well as infrastructure planning documents and energy systems models that incorporate grid extension and off-grid solution alternatives.

Fuller integration of both costs and benefits beyond household electricity use would make the EAD framework a more complete policy tool to consider cost–benefit tradeoffs implied by different electrification strategies. Further, increased data availability related to electricity access and use – particularly data collected from the same or similar households at different points in time – will allow for the expansion of this framework to specify the BAU baseline more accurately and to consider other electricity benefits that are missing in this article. That is, there is a need for better impact evaluations of the benefits of electrification – and the

https://doi.org/10.1017/bca.2024.14 Published online by Cambridge University Press

nuances of these relationships. In this article, we present the EAD as a general framework for estimating the dividends forgone along slow or incomplete electricity transitions. We apply the framework to the case of Honduras, a country that has made significant progress toward universal electrification yet is still looking for progress on both basic connections as well as improving quality and reliability. Our estimates for Honduras allow us to demonstrate the applicability of the EAD given data constraints and limitations. In the future, researchers could work to collect richer datasets that might allow for a more complete specification of the EAD. Nevertheless, as implemented, the EAD provides a valuable starting point for conceptualizing the dividends from electrification and comparing the dividends across electrification scenarios.

Supplementary material. The supplementary material for this article can be found at http://doi.org/10.1017/bca.2024.14.

Acknowledgments. We are grateful to Eric Burton who provided valuable research assistance and to Natacha C. Marzolf, Christine Eibs Singer, Hadley Taylor, Michelle Hallack, and Javier Cuervo for their help with various aspects of this study.

Funding statement. This work was supported by the Inter-American Development Bank.

Competing interest. The authors declare none.

References

Adair-Rohani, Heather, Karen Zukor, Sophie Bonjour, Susan Wilburn, Annette C. Kuesel, Ryan Hebert, and Elaine R. Fletcher. 2013. "Limited Electricity Access in Health Facilities of Sub-Saharan Africa: A Systematic Review of Data on Electricity Access, Sources, and Reliability." *Global Health: Science and Practice*, *1*(2): 249–261.

Alberini, A., J. Steinbuks, and G. R. Timilsina. 2020. *How Valuable is the Reliability of Residential Electricity Supply in Low-Income Countries?: Evidence from Nepal*. Washington, DC: World Bank Group, Development Economics, Development Research Group.

Angrist, Joshua D., and Jörn-Steffen Pischke. 2009. *Mostly Harmless Econometrics: An Empiricist's Companion*. Princeton University Press.

Bayer, Patrick, Ryan Kennedy, Joonseok Yang, and Johannes Urpelainen. 2020. "The Need for Impact Evaluation in Electricity Access Research." *Energy Policy*, *137*: 111099.

Bernard, Tanguy. 2012. "Impact Analysis of Rural Electrification Projects in Sub-Saharan Africa." *The World Bank Research Observer*, *27*(1): 33–51.

Beyene, Abebe D., Alemu Mekonnen, Marc Jeuland, and Sebastian Czakon. 2024. "Socioeconomic Impacts of Solar Home Systems in Rural Ethiopia." *Renewable and Sustainable Energy Reviews*, *192*: 114197.

Bhatia, Mikul, and Niki Angelou. 2015. *Beyond Connections: Energy Access Redefined*. World Bank.

Blimpo, Moussa P., and Malcolm Cosgrove-Davies. 2019. *Electricity Access in Sub-Saharan Africa: Uptake, Reliability, and Complementary Factors for Economic Impact*. World Bank Publications.

BN Americas. 2019. ENEE Will Invest $177 Million in the National Electricity Grid. BN Americas. https://www.bnamericas.com/en/news/enee-will-invest-177-million-in-the-national-electricity-grid.

Boardman, Anthony E., David H. Greenberg, Aidan R. Vining, and David L. Weimer. 2018. *Cost-Benefit Analysis: Concepts and Practice*. Cambridge University Press.

Boateng, Godfred O., Mobolanle R. Balogun, Festus O. Dada, and Frederick A. Armah. 2020. "Household Energy Insecurity: Dimensions and Consequences for Women, Infants and Children in Low-and Middle-Income Countries." *Social Science & Medicine*, *258*: 113068.

Bos, Kristine, Duncan Chaplin, and Arif Mamun. 2018. "Benefits and Challenges of Expanding Grid Electricity in Africa: A Review of Rigorous Evidence on Household Impacts in Developing Countries." *Energy for Sustainable Development*, *44*: 64–77.

Bush, Clarence Anthony. 2002. *On the Substitutability of Local Newspaper, Radio, and Television Advertising in Local Business Sales.* Federal Communications Commission, Media Ownership Working Group.

Chakravorty, Ujjayant, Martino Pelli, and Beyza Ural Marchand. 2014. "Does the Quality of Electricity Matter? Evidence from Rural India." *Journal of Economic Behavior & Organization*, *107*: 228–247.

Daka, Karen Rajaona, and Jérôme Ballet. 2011. "Children's Education and Home Electrification: A Case Study in Northwestern Madagascar." *Energy Policy*, *39*(5): 2866–2874.

Dale, Larry. 2008. An Analysis of the Price Elasticity of Demand for Household Appliances.

Dang, Duc Anh, and Hai Anh La. 2019. "Does Electricity Reliability Matter? Evidence from Rural Viet Nam." *Energy Policy*, *131*: 399–409.

Dhanaraj, Sowmya, Vidya Mahambare, and Poonam Munjal. 2018. "From Income to Household Welfare: Lessons from Refrigerator Ownership in India." *Journal of Quantitative Economics*, *16*: 573–588.

Diallo, Arouna, and Richard K. Moussa. 2020. "The Effects of Solar Home System on Welfare in Off-Grid Areas: Evidence from Côte d'Ivoire." *Energy*, *194*: 116835.

Fetter, T. Robert, and Faraz Usmani. 2020. *Fracking, Farmers, and Rural Electrification in India*, Vol. *864*. Ruhr Economic Papers.

Flores, Wilfredo C., Osvaldo A. Ojeda, Marco A. Flores, and Francisco R. Rivas. 2011. "Sustainable Energy Policy in Honduras: Diagnosis and Challenges." *Energy Policy*, *39*(2): 551–562.

Gertler, Paul J., Kenneth Lee, and A. Mushfiq Mobarak. 2017. Electricity Reliability and Economic Development in Cities: A Microeconomic Perspective.

Government of Honduras. 2010. República de Honduras Visión de País 2010–2018 y Plan de Nación 2010–2022. Government of Honduras. https://observatorioplanificacion.cepal.org/sites/default/files/plan/files/HondurasPlandeNacion20102022.pdf.

Grogan, Louise, and Asha Sadanand. 2013. "Rural Electrification and Employment in Poor Countries: Evidence from Nicaragua." *World Development*, *43*: 252–265.

Groh, Sebastian, Shonali Pachauri, and Narasimha D. Rao. 2016. "What Are We Measuring? An Empirical Analysis of Household Electricity Access Metrics in Rural Bangladesh." *Energy for Sustainable Development*, *30*: 21–31.

Holland, Peter, Pablo Alfaro, and David Evans. 2015. *Extending the School Day in Latin America and the Caribbean.* World Bank Policy Research Working Paper 7309.

Inter-American Development Bank (IADB). 2021. Effectiveness for Improving Lives. Inter-American Development Bank. https://www.iadb.org/en/topics-effectiveness-improving-lives/economic-analysis-overview.

International Energy Agency. 2017. Sustainable Development Goal 7: Ensure Access to Affordable, Reliable, Sustainable and Modern Energy for All. International Energy Agency. https://www.iea.org/reports/sdg7-data-and-projections/access-to-electricity.

Irwin, Bridget R., Klesta Hoxha, and Karen A. Grépin. 2020. "Conceptualising the Effect of Access to Electricity on Health in Low-and Middle-Income Countries: A Systematic Review." *Global Public Health*, *15*(3): 452–473.

Jacobson, Arne. 2007. "Connective Power: Solar Electrification and Social Change in Kenya." *World Development*, *35*(1): 144–162.

Jeuland, Marc, T. Robert Fetter, Yating Li, Subhrendu K. Pattanayak, Faraz Usmani, Randall A. Bluffstone, Carlos Chávez, *et al.* 2021. "Is Energy the Golden Thread? A Systematic Review of the Impacts of Modern and Traditional Energy Use in Low-and Middle-Income Countries." *Renewable and Sustainable Energy Reviews*, *135*: 110406.

Jeuland, Marc, Nils Ohlendorf, Rajah Saparapa, and Jan Christoph Steckel. 2020. "Climate Implications of Electrification Projects in the Developing World: A Systematic Review." *Environmental Research Letters*, *15*(10): 103010.

Jeuland, Marc, Jie-Sheng Tan Soo, and Drew Shindell. 2018. "The Need for Policies to Reduce the Costs of Cleaner Cooking in Low Income Settings: Implications from Systematic Analysis of Costs and Benefits." *Energy Policy*, *121*: 275–285.

Kemmler, Andreas. 2007. "Factors Influencing Household Access to Electricity in India." *Energy for Sustainable Development*, *11*(4): 13–20.

Khandker, Shahidur R., Douglas F. Barnes, and Hussain A. Samad. 2012. "The Welfare Impacts of Rural Electrification in Bangladesh." *The Energy Journal*, *33*(1): 187–206.

Khandker, Shahidur R., Douglas F. Barnes, and Hussain A. Samad. 2013. "Welfare Impacts of Rural Electrification: A Panel Data Analysis from Vietnam." *Economic Development and Cultural Change*, *61*(3): 659–692.

Khandker, Shahidur R., Hussain A. Samad, Rubaba Ali, and Douglas F. Barnes. 2014. "Who Benefits Most from Rural Electrification? Evidence in India." *The Energy Journal*, *35*(2): 75–96.

Kornek, Ulrike, David Klenert, Ottmar Edenhofer, and Marc Fleurbaey. 2021. "The Social Cost of Carbon and Inequality: When Local Redistribution Shapes Global Carbon Prices." *Journal of Environmental Economics and Management*, *107*: 102450.

Labandeira, Xavier, José M. Labeaga, and Xiral López-Otero. 2017. "A Meta-Analysis on the Price Elasticity of Energy Demand." *Energy Policy*, *102*: 549–568.

Lee, Kenneth, Edward Miguel, and Catherine Wolfram. 2020*a*. "Does Household Electrification Supercharge Economic Development?" *Journal of Economic Perspectives*, *34*(1): 122–144.

Lee, Kenneth, Edward Miguel, and Catherine Wolfram. 2020*b*. "Experimental Evidence on the Economics of Rural Electrification." *Journal of Political Economy*, *128*(4): 1523–1565.

Litzow, Erin L., Subhrendu K. Pattanayak, and Tshering Thinley. 2019. "Returns to Rural Electrification: Evidence from Bhutan." *World Development*, *121*: 75–96.

Llach, Juan, Cecilia Adrogué, María Gigaglia, and Catherine Rodriguez Orgales. 2009. "Do Longer School Days Have Enduring Educational, Occupational, or Income Effects? A Natural Experiment in Buenos Aires, Argentina [With Comment]." *Economía*, *10*(1): 1–43.

Luzi, Lucia, Abdul-Farouk Bemba Nabourema, Bryan Bonsuk Koo, Dana Rysankova, and Elisa Portale. 2020. *Honduras-Multi-Tier Framework (MTF) Survey*. World Bank Group. https://datacatalog.worldbank.org/dataset/honduras-multi-tier-framework-mtf-survey.

Marzolf, Natacha C., Emily L. Pakhtigian, Eric Burton, Marc Jeuland, Subhrendu K. Pattanayak, Jonathan Phillips, Christine Eibs Singer, *et al.* 2019. *The Energy Access Dividend in Honduras and Haiti*, Vol. *743*. Inter-American Development Bank.

McCollum, David L., Luis Gomez Echeverri, Sebastian Busch, Shonali Pachauri, Simon Parkinson, Joeri Rogelj, Volker Krey, *et al.* 2018. "Connecting the Sustainable Development Goals by their Energy Inter-Linkages." *Environmental Research Letters*, *13*(3): 033006.

Morrissey, James. 2019. "Achieving universal electricity access at the lowest cost: A comparison of published model results." *Energy for Sustainable Development*, *53*: 81–96.

Nordhaus, William D. 2017. "Revisiting the Social Cost of Carbon." *Proceedings of the National Academy of Sciences*, *114*(7): 1518–1523.

Office of Management and Budget, U. S. (OMB). 2003. *Circular A-4: Regulatory Analysis*. Office of Management and Budget.

OLANDE and IDB. 2020. *Energy Prices in Latin America and the Caribbean*. Latin American Energy Organization. http://www.olade.org/en/publicaciones/energy-prices-in-latin-america-and-the-caribbean-annual-report-april-2020/.

Ozturk, Ilhan. 2010. "A Literature Survey on Energy–Growth Nexus." *Energy Policy*, *38*(1): 340–349.

Patrinos, Harry Anthony, and George Psacharopoulos. 2020. "Returns to Education in Developing Countries." In *The Economics of Education*, pp. 53–64. Academic Press.

Pattanayak, Subhrendu K., Jui-Chen Yang, Dale Whittington, and K. C. Bal Kumar. 2005. "Coping with Unreliable Public Water Supplies: Averting Expenditures by Households in Kathmandu, Nepal." *Water Resources Research*, *41*(2): 02012.

Peters, Jörg, and Maximiliane Sievert. 2016. "Impacts of Rural Electrification Revisited–The African Context." *Journal of Development Effectiveness*, *8*(3): 327–345.

Peterson, L. George. 2003. *A Primer on Nonmarket Valuation* (Champ, Patricia A., Kevin J. Boyle, and Thomas C. Brown, Eds.), Vol. *3*. Dordrecht: Kluwer Academic Publishers.

Psacharopoulos, George, and Harry Anthony Patrinos. 2018. "Returns to Investment in Education: A Decennial Review of the Global Literature." *Education Economics*, *26*(5): 445–458.

Rapson, David. 2014. "Durable Goods and Long-Run Electricity Demand: Evidence from Air Conditioner Purchase Behavior." *Journal of Environmental Economics and Management*, *68*(1): 141–160.

República de Honduras. 2020. Informe Nacional Voluntario de la Agenda 2030: De la recuperación al desarrollo sostenible. República de Honduras. https://sustainabledevelopment.un.org/content/documents/26311VNR_2020_Honduras_Report_Spanish.pdf.

Sagebiel, Julian, and Kai Rommel. 2014. "Preferences for Electricity Supply Attributes in Emerging Megacities—Policy Implications from a Discrete Choice Experiment of Private Households in Hyderabad, India." *Energy for Sustainable Development*, *21*: 89–99.

Samad, Hussain A., and Fan Zhang. 2016. *Benefits of Electrification and the Role of Reliability: Evidence from India.* World Bank Policy Research Working Paper, 7889.

Samad, Hussain A., Shahidur R. Khandker, M. Asaduzzaman, and Mohammad Yunusd. 2013. "The benefits of solar home systems: An analysis from Bangladesh." World Bank Policy Research Working Paper 6724.

Stern, David I., Paul J. Burke, and Stephan B. Bruns. 2019. The Impact of Electricity on Economic Development: A Macroeconomic Perspective.

Sustainable Energy for All (SEforALL). 2017. Power for All, and Overseas Development Institute. "Why Wait? Seizing the Energy Access Dividend".

Van de Walle, Dominique, Martin Ravallion, Vibhuti Mendiratta, and Gayatri Koolwal. 2017. "Long-Term Gains from Electrification in rural India." *The World Bank Economic Review*, *31*(2): 385–411.

WageIndicator. 2021. Minimum Wages in Honduras with Effect from 01-01-2016 to 31-12-2016. Wage Indicator. https://wageindicator.org/salary/minimum-wage/honduras/archive-before-2019/minimum-wages-in-honduras-with-effect-from-01-01-2016-to-31-12-2016.

Washburn, Christian, and María Pablo-Romero. 2019. "Measures to Promote Renewable Energies for Electricity Generation in Latin American Countries." *Energy Policy*, *128*: 212–222.

Watkiss, Paul, and Chris Hope. 2011. "Using the Social Cost of Carbon in Regulatory Deliberations." *Wiley Interdisciplinary Reviews: Climate Change*, *2*(6): 886–901.

Whittington, Dale, and Joseph Cook. 2019. "Valuing Changes in Time Use in Low-and Middle-Income Countries." *Journal of Benefit-Cost Analysis*, *10*(S1): 51–72.

Winkler, Harald, André Felipe Simões, Emilio Lèbre La Rovere, Mozaharul Alam, Atiq Rahman, and Stanford Mwakasonda. 2011. "Access and Affordability of Electricity in Developing Countries." *World Development*, *39* (6): 1037–1050.

World Bank. 2010. *Encuesta de Niveles de Vida 2008, Panama*. World Bank Group. https://microdata.worldbank.org/index.php/catalog/70.

World Bank. 2020. International Energy Agency, International Renewable Energy Agency, United Nations Statistics Division, and World Health Organization. The Energy Progress Report. https://trackingsdg7.esmap.org/data/files/download-documents/tracking_sdg_7_2020-full_report_-_web_0.pdf.

World Bank. 2021. *World Bank Open Data*. World Bank Group. https://data.worldbank.org/.

Cite this article: Pakhtigian, Emily L., Marc Jeuland, Subhrendu K. Pattanayak, and Jonathan Phillips. 2024. "Estimating Lost Dividends from Incomplete Energy Access Transitions." *Journal of Benefit-Cost Analysis*, doi:10.1017/bca.2024.14