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# Pathways to achieve universal household access to modern energy by 2030

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## Abstract

A lack of access to modern energy impacts health and welfare and impedes development for billions of people. Growing concern about these impacts has mobilized the international community to set new targets for universal modern energy access. However, analyses exploring pathways to achieve these targets and quantifying the potential costs and benefits are limited. Here, we use two modelling frameworks to analyse investments and consequences of achieving total rural electrification and universal access to clean-combusting cooking fuels and stoves by 2030. Our analysis indicates that these targets can be achieved with additional investment of US\$2005 65–86 billion per year until 2030 combined with dedicated policies. Only a combination of policies that lowers costs for modern cooking fuels and stoves, along with more rapid electrification, can enable the realization of these goals. Our results demonstrate the critical importance of accounting for varying demands and affordability across heterogeneous household groups in both analysis and policy setting. While the investments required are significant, improved access to modern cooking fuels alone can avert between 0.6 and 1.8 million premature deaths annually in 2030 and enhance wellbeing substantially.

**Keywords:** modern energy access, energy poverty, cooking fuel and stove choices, electrification, developing countries

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## 1. Introduction

More than 125 years after the invention of the incandescent bulb, over 20% of the world's population still lives

without electric lighting [1], and about 40% do not own a television [2]. Despite increasing rhetoric on the need to improve access to clean-burning fuels and electricity globally, the number of households depending on solid fuels is increasing and the number of new electricity connections in sub-Saharan Africa is outpaced by population growth [1, 3, 4].

A lack of access to modern energy sources and services accentuates inequities, impacts welfare, damages health,



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and impedes development for billions of people [5]. The recent Global Burden of Disease study estimates almost four million people die annually from household air pollution caused by traditional cooking fuels [6]. Time devoted by women and young children to obtaining traditional fuels restricts educational and economic opportunities [7]. Without electricity, households have inadequate lighting, communications and entertainment services and communities have limited access to essential services like healthcare and public lighting [8]. Finally, the combustion of biomass fuels in traditional stoves produces greenhouse gases [9] and aerosols such as black carbon [10]. Extensive use of biomass can also result in forest, land, and soil degradation, leading to net CO<sub>2</sub> emissions.

These concerns prompted the UN to declare 2012 the 'International Year of Sustainable Energy for All' with universal access to modern energy by 2030 as one of the stipulated objectives [11]. Global analyses of benefits of and investments for improving household energy access are limited [12–14], while earlier studies have largely been local, regional, or national, and focused predominantly on the technical and economic aspects of expanding energy infrastructure and supply [15, 16]. Electrification options for rural areas of developing countries are more widely assessed [17, 18] but, there is little quantitative analysis of options for accelerating a transition to cleaner-combusting cooking fuels or devices [19–21].

Here we assess investments required and impacts of achieving total rural electrification and universal access to clean-combusting cooking fuels and stoves by 2030 using two alternative modelling frameworks. We explore different policy pathways, their cost-effectiveness, and explicitly consider the ability of heterogeneous population groups to afford new fuels and stoves. We focus on populations in South and Pacific Asia and sub-Saharan Africa that account for 85% of the global unelectrified population and 70% of those without modern fuels or stoves.

## 2. Methodology

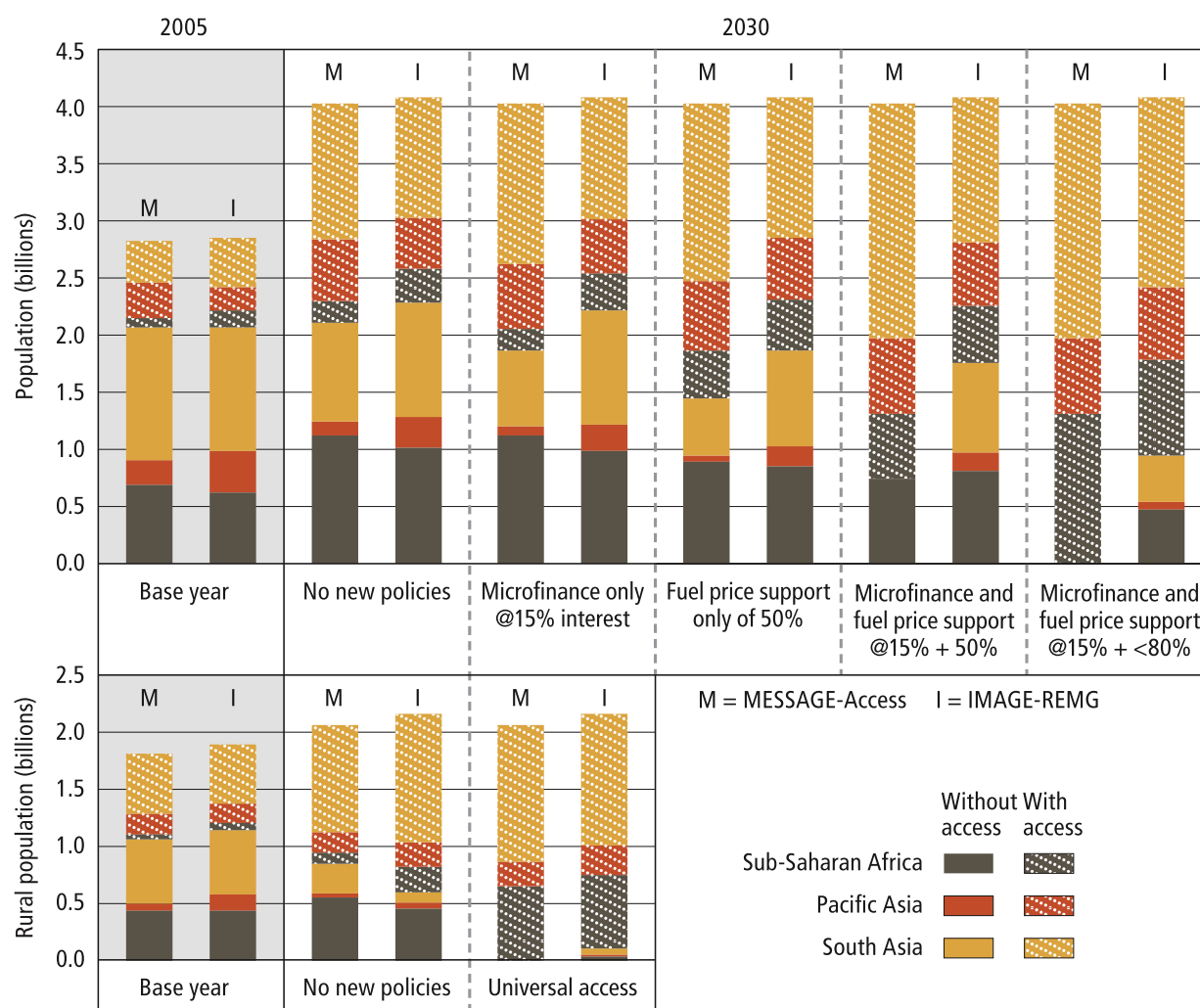
We use MESSAGE-Access [19, 22, 23] and IMAGE-REMG [24, 25] (see the supporting information (SI) available at [stacks.iop.org/ERL/8/024015/mmedia](http://stacks.iop.org/ERL/8/024015/mmedia) for further description and references), both extensions of two widely used integrated assessment models, to explore alternative policy pathways for achieving universal access to modern energy by 2030. The use of these two alternative modelling frameworks allows us to better account for uncertainties with data and methodologies. The models use different descriptions of energy choices, access and affordability for heterogeneous socio-economic populations and demand densities at a fine spatial scale. We use national household survey data from key countries and regions, and national and international energy and economic data to calibrate the models (see SI, table S1 and figures S1 and S2). Both models distinguish among rural and urban households belonging to five or more expenditure groups in each model region (table S2). Using different methods, both models choose a low

total cost energy-equipment combination to satisfy household energy demands within budget limitations.

Our analysis of future scenarios of electrification and transitions to modern cooking fuels and stoves use the same modelling frameworks, but are distinct. The future policy scenarios that we analyse for accelerating a transition to clean-combusting cooking fuels and stoves include those that decrease upfront capital investments and recurrent fuel costs, such as grants, credit and fuel subsidies. Four different sets of policy scenarios are explored: (a) no new policies, (b) fuel price support only, (c) finance through grants or easier and cheaper access to credit for upfront investments, and (d) fuel price support coupled with stove grants or easier credit access. The basic premise of our modelling analysis and scenario construction is that people aspire to an LPG-like experience for cooking. This is not to imply that LPG is the only or ideal choice in all cases, but that people aspire to a cooking experience in terms of convenience, efficiency and emissions similar to that provided by the standard and existing technology associated with an LPG stove and fuel combination [26]. In reality, LPG will not be the preferred nor perhaps even the most cost effective option in every case.

Both models assume that once connected to a grid, electricity is the preferred energy choice for lighting and running appliances. We estimate expansions needed to transmission and distribution networks to connect all rural populations to a grid and related costs for meeting household electricity needs in a scenario with no additional policies, compared to a scenario with a minimum demand threshold of 420 kWh per year (enough for lighting and running some small appliances as specified in [5]) per household for the universal access case. For the rural electrification scenarios, we estimate demand based on changes in population, income and access over time (see SI). Electricity infrastructure expands in the models using a generalized grid design and population density information on  $0.5^\circ \times 0.5^\circ$  grid cells, using technology that is commonly used for rural electrification, described in [24, 27]. Both models estimate the amount by which generation and grid capacity would need to expand in order to meet the increased demand from the rural sector for a universal access target to be achieved by 2030. In this analysis, we consider only grid-based power supply for expanding rural electricity access. However, we also carry out an ex-post sensitivity analysis, to explore the potential and cost implications of using mini-grid and off-grid technologies rather than central grid-based power. We do this by comparing the costs of centralized electricity production to mini-grid and off-grid alternatives for each rural population group, and assume that the mini-grid or off-grid option is preferable when its levelized costs of electricity, including generation, transmission and distribution, is lower than that of centrally produced power (see SI and table S9). In reality, factors other than costs like political and security concerns might also influence the choice between grid and off-grid options, but we do not account for these in our models.

To estimate the total investment needs for expanding grid electricity access to rural populations, we include the costs of grid extension, operation and maintenance of the power



**Figure 1.** (A) Populations dependent on modern and traditional cooking fuels under alternative policy scenarios. (B) Rural electrified populations under no new policy and total rural electrification scenarios.

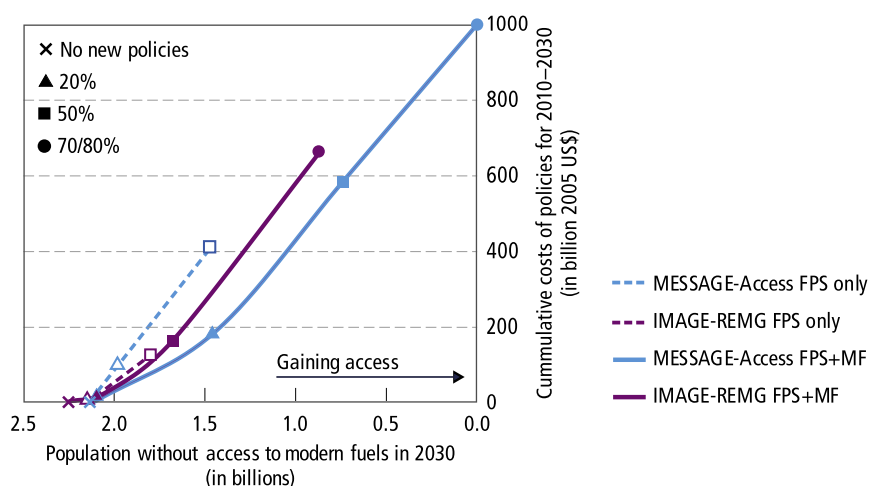
system and investments for additional electricity generation. The total policy costs for access to modern fuels and stoves are estimated as the sum of the costs of fuel price support (subsidy), new LPG stoves, and improved biomass stoves (see SI).

We use the standard WHO methodology described in [28] and documented in [29], to estimate the number of deaths attributable to solid fuel use in homes in the base year and in 2030 for a scenario with no new access policies. We use household dependence on solid fuels as a proxy for actual exposure to household air pollution. Estimates of relative risks for household air pollution related diseases are sourced from [20, 28]. We estimate deaths for those diseases with strong epidemiological evidence for an enhanced risk due to solid fuel use. The analysis of health impacts due to solid fuel use include the mortality and morbidity effects on adults over the age of 30 years as well as on children below the age of 5 years.

Finally, we estimate changes in greenhouse emissions due to universal access policies and targets using standard IPCC emissions factors.

### 3. Results

Without significant additional investments and dedicated policies, our analysis suggests that the goal of total rural electrification and universal access to modern cooking fuels and stoves by 2030 is unachievable. Figure 1(a) shows changes in access to modern cooking energy services by 2030 for alternate policy scenarios. Our analysis suggests that in the absence of new policies, an additional 50–220 million people in sub-Saharan Africa, South and Pacific Asia would rely on traditional solid fuels and stoves, compared to 2005. Scenarios that combine fuel price support with grants or low-cost financing for stove purchases are the most effective in achieving universal access to modern cooking fuels and stoves by 2030 (figure 2). Neither of these policies alone is sufficient for achieving this target. Costs increase with the stringency of the policy, and particularly with the level of fuel price support. Higher price support results in increased access with a larger number of people switching to modern fuels. We estimate the additional policy costs for enabling access to modern cooking fuels and stoves for all by 2030 in these regions to be between US\$<sub>2005</sub>757 and US\$<sub>2005</sub>998



**Figure 2.** Effectiveness of alternate policy scenarios in improving access to modern cooking energy carriers and stoves. Cost curves shown separately for both models and for scenarios where only fuel price support (FPS) policies are implemented and scenarios where both fuel price support and microfinance loans (FPS + MF) are made available. The distinct markers depict differing fuel price support levels.

billion over 20 years. Our estimates are significantly higher than indicated by previous studies [12, 14] which account only for the initial capital costs of improved stoves and deposit or connection fees, but do not estimate additional subsidies required to lower modern fuel costs in order to make them affordable to the poorest.

Without policies to accelerate electrification, between 480 and 810 million additional people are estimated to gain access to electricity by 2030, but 600–850 million people in rural South and Pacific Asia and sub-Saharan Africa could remain without electricity (figure 1(b)). Providing grid electricity to all rural households by 2030 requires an additional generation capacity of between 21 and 28 GW. We estimate the additional investment for rural electrification is between US\$<sub>2005</sub>183 and US\$<sub>2005</sub>258 billion between 2010 and 2030. This is towards the mid-range of estimates reported previously [14]. The differences in our estimates compared to previous ones stem from differences in methodologies and assumptions regarding average electricity use and capacity expansions required.

Our electrification investment estimates may be considered an upper bound as decentralized systems for meeting basic lighting and electricity demands are likely to be a more viable option in remote areas with low population and demand densities [30]. Previous analysis suggests that the electrification needs of a significant fraction of the rural population in some regions could be met by decentralized systems [24, 31]. In this case, investments are likely to be lower compared to our estimates where all access is achieved via grid extension alone (see SI and table S9 for sensitivity results of the potential for decentralized options). However, the competitiveness of decentralized options is sensitive to demand levels. Thus, while such options may be competitive in the short term in areas with low demand and population densities, they may not pay off in the long-run as communities develop and electricity demand grows beyond basic needs.

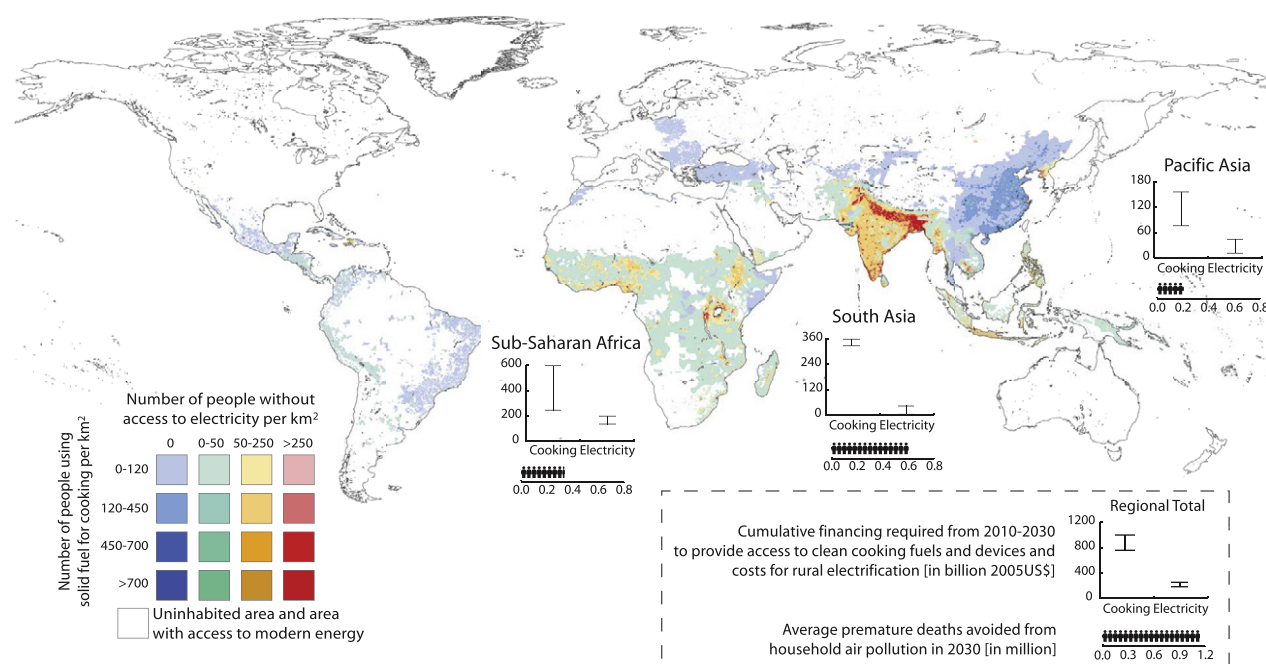
Our analysis thus suggests that achieving near universal access to electricity and clean cooking by 2030 will require

additional investments of between US\$<sub>2005</sub>47–62 billion per year in the three regions analysed in this work (figure 3), approximately half of current Global Official Development Assistance (ODA) [32], but only 3–4% of current investments in the global energy system. If we assume that costs in the rest of the world are similar to the regions of focus in this analysis, then globally US\$<sub>2005</sub>65–86 billion per year would be required to achieve these goals by 2030. Much of this investment (US\$<sub>2005</sub>19–40 billion per year) will need to occur in sub-Saharan Africa. While this is a significant sum, improved access to modern cooking fuels alone can potentially reduce premature deaths attributable to solid fuel use by 0.6–1.8 million per year in 2030, in the study regions (figure 3 and table S8). This would eliminate a major environmental cause of death [33]. This includes between 0.3 and 0.4 million fewer deaths of children below the age of five in 2030.

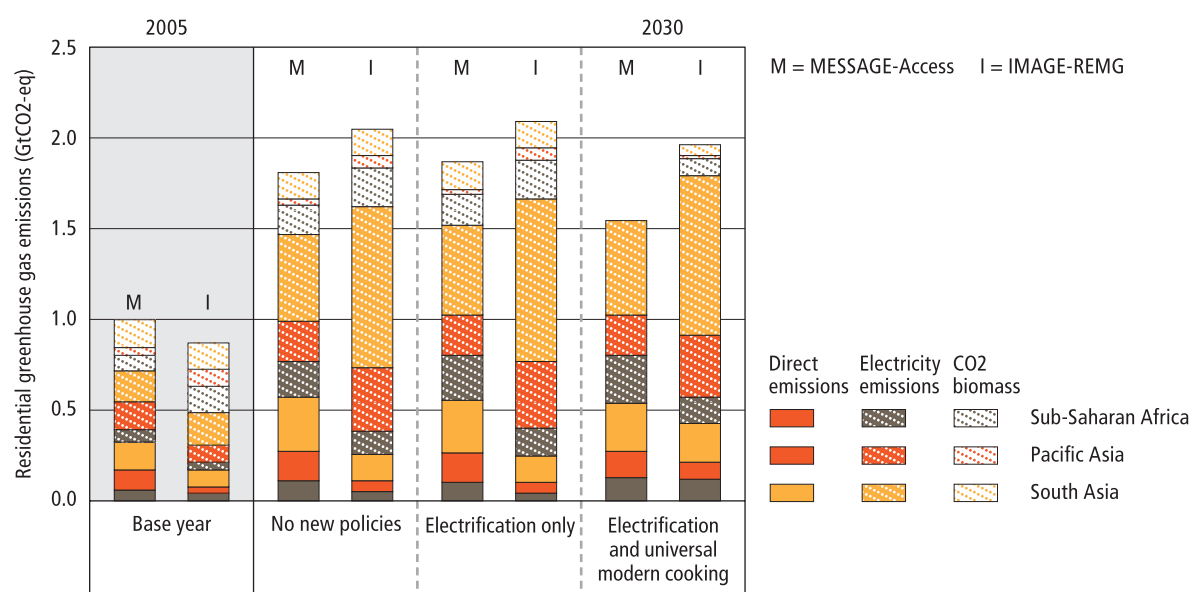
Shifting to cleaner cooking fuels such as petroleum based LPG and expanding electrification, with electricity often generated using fossil fuels, might seem at odds with global efforts towards a low-carbon economy. However, access policies will increase fossil energy demand by less than 2–4 EJ in 2030 (comparable to 20%–40% of current transport sector energy use in these regions), but could displace 12–15 EJ of traditional biomass use (see SI and figure S5). While total rural electrification alone results in a marginal increase in total residential sector energy demand (1%–2% over the scenario with no new policies), providing access to modern energy for cooking will lead to a decrease in final residential energy use by 2030 by 31–46%. This is because LPG stoves are about four times more efficient than biomass stoves, and hence, require less input energy to provide the same amount of useful energy for cooking.

Hence, improved access will have negligible GHG impacts and could improve household and local air quality (figure 4 and table S7). This might be the case even if access is provided entirely from fossil energy sources. This is because transitioning to such fuels will displace large





**Figure 3.** Current global distribution of population without access to modern cooking and electricity with estimates of cumulative costs for achieving total rural electrification and universal modern cooking access by 2030 and deaths avoided in 2030.



**Figure 4.** Residential sector greenhouse gas emissions for different access scenarios. Emissions are differentiated by whether they are a result of direct combustion of fuels in households; upstream emissions associated with electricity use; or emissions associated with the incomplete combustion of traditional biomass. CO<sub>2</sub> emissions from traditional biomass are based on an assumption that 20% is unsustainably harvested. Note: the modern cooking case depicted refers to the scenario with microfinance at 15% interest rate and >50% fuel price support policies.

quantities of traditional biomass use. Current technologies that use traditional biomass are associated with significant emissions of non-CO<sub>2</sub> Kyoto gases (e.g. CH<sub>4</sub>, N<sub>2</sub>O) and aerosols (e.g. BC, OC) due to incomplete combustion [34]. In this analysis, we include only Kyoto gases in our estimates of emissions. The IEA estimates that achieving universal modern energy access by 2030 would raise CO<sub>2</sub> emissions

alone as compared to their current practices scenario by only 0.7% [12]. We estimate that achieving total rural electrification alone will increase GHG emissions by about 2%–4% over the baseline in 2030. However, meeting a target of rural electrification and universal access to modern cooking could reduce total GHG emissions compared to the baseline if one accounts for avoided emissions from traditional biomass

use and further assumes that 10–20% of biomass used in the residential sector is unsustainably harvested (as assumed in [21]).

#### 4. Discussion

Our analysis is a first attempt to assess the costs and implications of pathways to achieve total rural electrification and universal access to modern cooking, employing two global modelling frameworks using harmonized assumptions. The study focuses on results aggregated for large world-regions and provides a comprehensive picture of the amount of effort required to reach universal access by 2030 and other implications of this target. This information is essential for determining the scale of financial requirements and setting appropriate policies to meet these goals. The analysis incorporates some of the heterogeneity of local and national situations. Heterogeneity in demands and paying abilities of populations across rural and urban areas and across disparate income groups in these regions is accounted for, as is the population density across regions. Incorporating such heterogeneity reveals that energy use patterns among the world's poor have remained virtually unchanged over the last century, despite significant technological advances and an increasing array of energy services enjoyed by some. It is clear that despite the potential benefits, enabling greater modern energy access globally will not be easy: it requires mobilizing significant additional financing; ensuring technologies deployed are affordable and acceptable to local communities; and that local capacity and institutions are developed to ensure efforts are sustainable in the long term.

There are some caveats to the results presented here. In our analysis, we have not addressed the potential changes in (spatial) population distribution. This implies that in scenarios with more rapid urbanization than assumed here and a lower rural population density, rural electrification could be more expensive. The opposite may obviously hold if rural population density increases in parts of sub-Saharan Africa, due to either low urbanization or high population growth rates in rural areas. In that case, reaching full access might be cheaper and with different technologies than shown in this study.

In the analysis, we have used one single scenario for electricity demand and investment costs, both of which influence the total required investments and the potential for mini-grid and off-grid technologies. At lower demand levels, less total investment is needed, and grid-based electrification is less competitive compared to small-scale technologies. At higher demand levels, the total investment needs increase, and the potential for mini-grid and off-grid technologies reduces. Similarly, the results differ if alternative costs for grid components are assumed. A broader analysis of these uncertainties can be found in [24].

Finally, our conclusions about the feasibility of achieving universal access goals refer to the technical and economic feasibility in a more-or-less optimal world. Real world policies may, however, need to be adapted to actual political realities (for instance, they may need to be robust against

corruption and leakage). As a result, such policies can certainly be different from the ones analysed here and this may, in turn, influence their relative cost-effectiveness. At the same time, the technical options included in our models have focused on the most widespread, currently. A wider array of actual choices exists and the options selected will ultimately need to be context specific and suited. While acknowledging the uncertainties in design, implementation and costs of policies at a national and sub-national level, our results emphasize the overall scale of efforts required and the wider impacts of achieving access goals.

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