Energy and Health in Low-Income and Middle-Income Countries 2

Beyond access: clean energy use in low-income and middle-income countries

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Access to clean energy—here defined as electricity, liquefied petroleum gas, biogas, and ethanol—has increased substantially in low-income and middle-income countries over the past three decades. However, millions still lack reliable and affordable access to electricity and clean cooking fuels. This Series paper explores the drivers of clean energy adoption, assesses tools for tracking progress, and examines persistent barriers—including high costs, unreliable supply, and insufficient availability. Simplistic metrics, such as Sustainable Development Goal 7's binary indicators (eg, whether an individual has an electricity connection or not), risk overstating the health and equity impacts of energy transitions by overlooking fuel stacking, dynamic consumption patterns, and the gendered burden of polluting fuels. Drawing from historical trends and national policies, we show how targeted subsidies, robust supply chains, and coordinated investments have spurred increased clean fuel use. Meaningful gains require moving beyond technical fixes to inclusive, evidence-based strategies that address inequities, ensure affordability and reliability, and deliver lasting health benefits.

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Introduction

Reliable and affordable clean energy—such as electricity and gas—is essential for modern living and powering economies. Clean energy fuels everyday activities such as cooking, lighting, and heating; drives labour-saving and time-saving appliances; supports access to information and communication; and powers essential income-generating activities and health-care services. Moreover, clean energy is central to health: it improves nutrition through modern agricultural practices and food preservation, supports access to safe water, and provides protection against extreme temperatures (figure 1). In short, access to and continued use of clean energy is a public health necessity.

Throughout human history—and still in many parts of the world now—core energy needs have been met by burning solid fuels such as firewood and charcoal. Although this practice has long provided essential energy, it also releases harmful pollutants that damage health[3] and contribute to climate change.[4] By contrast, burning gas produces fewer harmful pollutants, and electricity—which is not burned at the point of use—is even cleaner. Over the past century, the shift to commercial fuels (eg, electricity and gas) has improved energy efficiency and reduced environmental impacts.

However, even these cleaner energy sources present challenges. The production and combustion of fossil fuels such as oil, gas, and coal to generate electricity contribute substantially to air pollution—the world's largest environmental risk factor for ill health—and are the primary driver of human-caused climate change. And despite grid expansion and strengthening in low-income and middle-income countries (LMICs),[5–7] many households still rely on polluting fuels to meet daily energy needs. More than 2 billion people rely on biomass fuels for cooking, lighting, and heating globally, with the vast majority of them living in LMICs.[6] Individuals and communities are consequently directly exposed to harmful air pollutants that cause between 2 and 5 million premature deaths each year—including about 7% of all deaths among children younger than 5 years.[3] Even these sobering data are likely to under-represent the extent of inequities in energy access and their resulting health consequences, which are concentrated among the most poor, the most remote, and the most politically disenfranchised individuals. These populations are both literally and figuratively powerless to secure a healthier future.

Sustainable Development Goal (SDG) target 7.1 commits the global community to ensuring "universal access to affordable, reliable, and modern energy" by 2030.[6]

Key messages

- Clean energy is central to global health, yet billions depend on polluting fuels
- Economic constraints are the primary determinants of fuel choices and therefore health outcomes
- Current metrics for clean energy access exaggerate progress and obscure health risks
- Targeted subsidies, robust supply chains, and coordinated investments have driven progress
- More rigorous causal evaluations of clean energy policy's health and climate impact are needed
- Streamlined, transparent funding is essential to meet health and climate goals

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However, projections indicate that this target will be missed. In many LMICs, especially countries in sub-Saharan Africa, where more than 600 million people remain without electricity, economic growth has not translated into widespread clean energy access or substantial reductions in fuel costs. Moreover, clean energy uptake has been only partly responsive to policy initiatives, which have been constrained by infrastructure deficits and insufficient financing. To compound the issue, metrics for monitoring progress, such as the indicators for the SDG 7 targets, focus on clean energy access and overlook issues of reliability, quality, and affordability, which shape people's actual use, and therefore health. This narrow focus risks overstating progress and impedes the design of initiatives required to more completely realise the full transition to clean energy that is needed to improve public health.

This paper is the second in a Series examining the relationship between clean energy and health in LMICs. The connection between the two is widely acknowledged, but a growing body of research has documented barriers to clean energy adoption that hinder the realisation of health benefits from clean energy. Although studies have recognised the roles of high prices, supply disruptions, and behavioural frictions in clean energy adoption and continued use,[1,8–14] previous work has been narrow in its focus on either electricity or cooking, on specific drivers or aspects of fuel use, on single interventions, or on local case studies that are difficult to generalise.

In this Series paper, we draw together evidence from multiple regions and sectors to offer an integrated view of clean energy access and its implications for health. We outline historical trends in energy access, describe how progress is measured, examine the forces that have driven gains in clean energy adoption and use, and discuss how these trends, progress, and forces have (or have not) translated into better health outcomes. We focus on the impacts of energy on health and wellbeing in rural, periurban, and urban settings, with particular attention to individual and household needs. Limitations in data and evidence constrain the depth of our analysis of enterprises, health-care facilities, and community institutions; therefore, we focus on household energy access and use. Similarly, although transportation, power generation, energy-related disasters, and climate change also affect health, we exclude those topics from our focus. This paper establishes for the Series a common understanding of what energy access means, how this progress connects to health, and what policies have (or have not) worked to expand it.

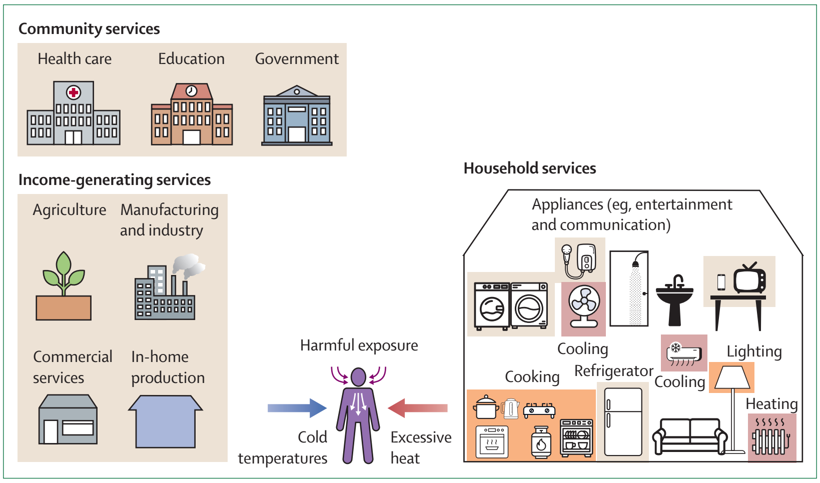

Figure 1: **Key energy services that are integral to health and wellbeing, including cooking, heating, cooling, lighting, appliances (eg, for communication and entertainment), income generation (industrial, commercial, and in-home generation), and agricultural (eg, irrigation and pumping), health care, and educational services**

We distinguish these uses based in part off definitions drawn from Jeuland et al[1] and Angelou and Bhatia.[2] Access to and use of clean energy services can both reduce exposure to air pollution (orange shading), protect users from extreme environmental conditions (pink shading), and provide access to health promoting technologies and goods (tan shading).

Trends in energy access and use and health

Global access to electricity and clean cooking has increased in recent decades, but these gains have been partly offset by rapid population growth in regions with persistently low clean energy access. Electricity access worldwide rose from about 73% in 2001, to 92% in 2023, while clean cooking access increased more modestly, from 52% to 74% over the same period (figure 2); most of this progress has occurred in urban areas. In 2023, 666 million people still lacked access to electricity (451 million in rural areas alone), and 2·1 billion relied primarily on polluting cooking fuels (1·5 billion in rural areas).[6]

These trends correlate with health improvements. Between 2001 and 2021, estimates of the global burden of disease attributable to household air pollution declined: disability-adjusted life-years fell from 192 million to 111 million, and deaths dropped from 4·9 million to 3·1 million. Evidence from observational studies and randomised trials shows that exclusive use of gas or electricity yields far lower household air pollution concentrations than do fuels such as wood, charcoal, or kerosene.[15]

Gas (ie, liquefied petroleum gas [LPG], natural gas, and biogas) is the most used clean-burning cooking fuel globally, serving roughly 90% of households relying primarily on clean fuels. In Europe, Africa, and China, gas is used by 75% of clean fuel households (the remainder use electricity), whereas in the Americas this figure reaches nearly 95%. Where polluting fuels remain dominant, biomass (ie, wood, crop waste, and dung) is the main cooking fuel, with charcoal serving as a common alternative, particularly in Africa.[6,16]

By 2030, 92% of the global population is projected to have access to electricity, but only 79% will be primarily cooking with clean fuels.[6] This projection implies that 660 million people will be without electricity and 1·8 billion people will be cooking primarily with polluting fuels, the majority of whom will live in sub-Saharan Africa. Although further declines in the disease burden attributable to polluting fuels are expected, substantial

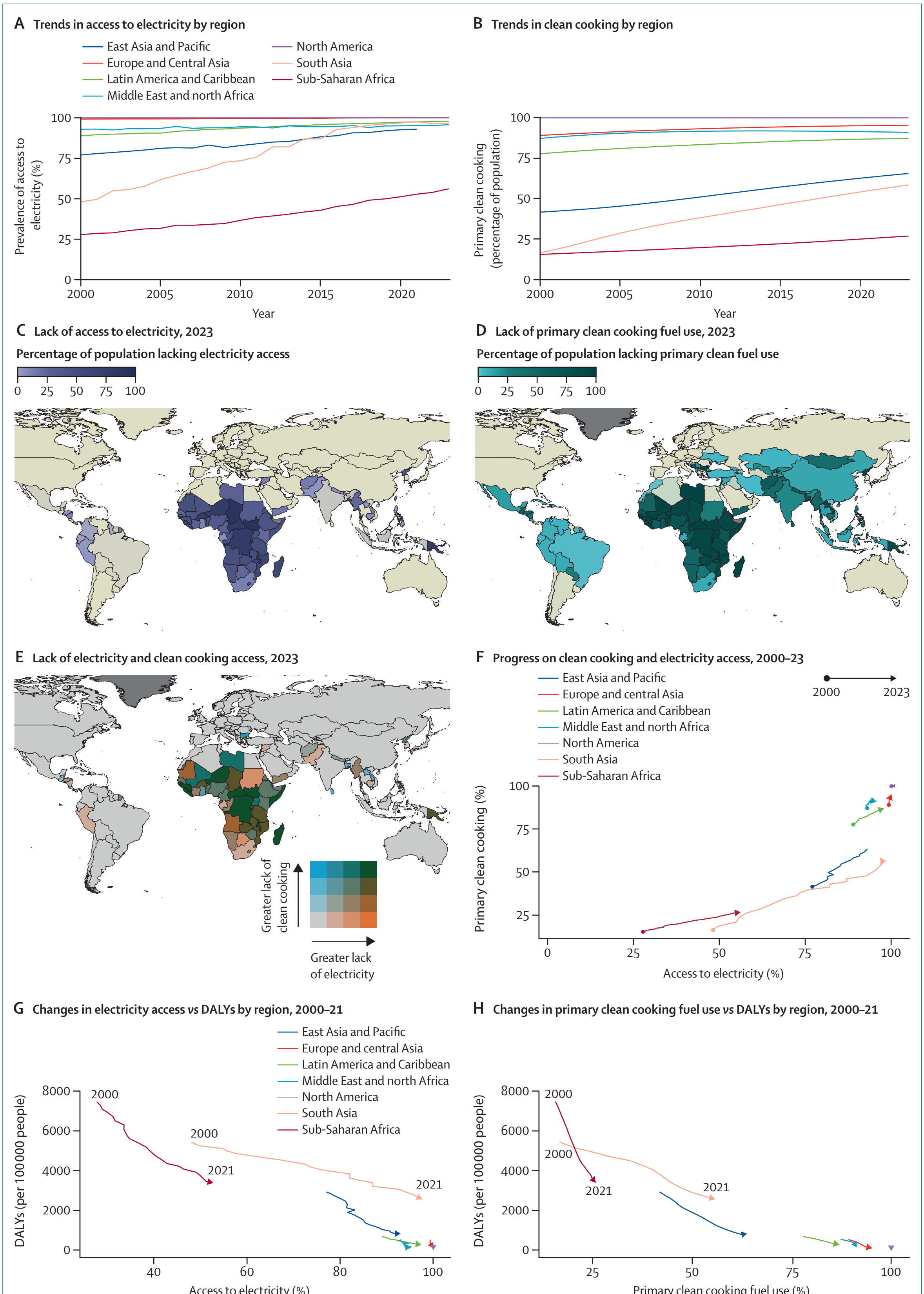

***Figure 2:* Global trends in access to electricity and clean cooking fuels**
Regional historical progress on electricity (A) and primary clean fuel (B) use according to Sustainable Development Goal 7's tracking indicators. Country-level rates of access to electricity (C) and primary clean fuel (D) use as of 2023. (E) The interaction between inadequate access to both electricity and primary clean fuel use, and whether countries are behind on one or the other or both. Colour breaks occur at the 66th, 75th, and 90th centiles of electricity and cooking access, separately, for all countries. (F) The trajectory of progress on electricity and primary clean fuel use by region from 2000 to 2023. Figures draw on data from the Energy Sector Management Assistance Program's 2024 annual report.[6] The relationship between energy (G) and clean cooking access (H) and the number of attributed disability-adjusted life-years (DALYs) per 100 000 people across regions.

Panel: A historical perspective on Africa's persistent clean energy challenge

In the USA, the Rural Electrification Administration and the 1936 Rural Electrification Act provided federal loans to cooperative power companies for the installation of electrical distribution systems in isolated rural areas. These efforts resulted in 90% rural electrification by the 1950s, reducing infant mortality by 15% to 19% and improving health and wellbeing by providing light, refrigeration, pumped water, and easier clothes washing, all of which promoted hygiene and reduced the relative time costs of investing in child health.[23,24] The USA reached universal access by 1985, and similar rural electrification efforts occurred across Europe during this time.[25,26]

By contrast, colonial powers in sub-Saharan Africa prioritised electricity infrastructure to support industrial facilities and urban street lighting, largely ignoring household needs.[7] After gaining independence in the 1960s, governments relied on industrial offtakers—large-scale industries that could provide stable demand for electricity—but they struggled to fund broader electrification and relied on World Bank loans. Progress stalled during the debt crisis and structural adjustment programmes of the 1990s and early 2000s.[27] In the past two decades, electricity-generating capacity has remained stagnant. Nowadays, 70% of utilities in sub-Saharan Africa remain government-owned and vertically integrated, with inefficiencies due to limited competition, transparency, and oversight.[28]

Sub-Saharan Africa faces distinct challenges in achieving universal energy access compared with those faced by high-income countries. First, utility business models in high-income countries relied on substantial government intervention and fiscal subsidies, with minimal dependence on private capital seeking financial returns. Without comparable public support, these models are unlikely to succeed in low-access regions. Second, when high-income countries achieved near-universal access, households were far wealthier than those in low-access regions nowadays, enabling them to afford connection fees, energy services, and appliances, which supported utility financial stability. Third, key features of modern energy systems—such as centrally coordinated wholesale markets, independent regulators, and private market players—emerged only after universal access was achieved in high-income countries. To achieve universal energy access, and the associated improvements in health, African utilities should operate under fundamentally different conditions and adapt their strategies to meet the unique challenges of their context.

health impacts from household air pollution will persist and will be concentrated among the poorest and most marginalised populations.

After acknowledging that SDG 7 is unachievable in many places, some countries have adopted more modest targets. For example, Ghana aims to achieve 50% adoption of LPG for cooking by 2030, with 70% adoption in rural areas by 2070.[17] As of 2021, 37% of Ghanaian households used LPG in some capacity,[18] and trends suggest the country is on track to meet its 2030 target. However, because these targets measure adoption as any use of LPG, regardless of any other fuels used in parallel, households covered in these metrics will likely continue to rely on polluting fuels.

Energy access in health-care facilities and educational settings is also essential for human development. Nearly 1 billion people in LMICs are currently served by health-care facilities that lack reliable electricity (478 million) or have no electricity at all (433 million). Evidence suggests that providing just 30 000 of these primary health facilities with electricity could save up to 7·8 million lives by 2050 (see the fourth paper in this Series for more on energy access in health facilities).[19] In 2021, only 28% of primary schools in LMICs had reliable electricity, and 79% had some form of access.[20] Moreover, other sectors essential to development, such as commercial enterprises, government buildings, community facilities, and irrigated agricultural land, also have inadequate access to electricity, although no global data exist on the energy sources powering these services.

Drivers of clean energy access and use

Universal access to clean energy in high-income countries—and the resulting reductions in pollution exposures and deaths—was not achieved as a natural consequence of economic growth, but was instead the result of deliberate government intervention and fiscal subsidies.[21,22] These governments made substantial investments in energy infrastructure, using fiscal tools to reduce the costs of electricity generation, distribution, and household access. Such efforts were supported by political and economic systems that treated electricity and clean cooking fuels as essential public services. By contrast, sub-Saharan Africa, which is home to nearly 90% of the world's population that lacks basic electricity and cooking services, suffers from a legacy of colonialism that has left its electricity infrastructure underdeveloped. The region's history has created serious financing challenges in the post-independence era, as well as unique obstacles to achieving universal energy access and its associated health gains (panel).

Access to electricity and clean cooking fuels in LMICs is consistently higher in urban areas, near markets and other infrastructure, and among populations with higher incomes and levels of formal education.[8,18,29–34] This uneven progress reflects both demand-side barriers, such as affordability and reliability, and supply-side constraints, such as weak infrastructure.

Affordability has a major role in driving adoption of both electricity and clean cooking. For both grid electrification and cleaner cookstoves, randomised controlled trials in multiple LMIC settings have shown that substantial price reductions are necessary to drive uptake.[31,35–40] High recurring fuel costs can also discourage initial adoption of clean energy technologies, as the inability to afford ongoing fuel expenses can deter initial investments.[41,42]

Fuel prices shape both total energy consumption and the use of specific fuels. Wealthier households with higher social capital typically consume more fuel, whereas households with fewer financial resources might have suppressed demand due to affordability constraints.[43] High electricity costs relative to incomes can restrict use, even when connections are highly subsidised.[44,45] Similarly, clean cooking fuel use increases when prices are reduced, as shown in small-scale programmes and natural experiments.[38,46] The opposite is also true: price increases cause reductions in clean fuel use and reversion to polluting fuels.[47]

Reliable, easy access to clean fuels makes consistent use possible, in turn sustaining lower pollution exposures. Poor-quality electricity supply—characterised by frequent outages and low voltage—reduces the value of grid connections and demand.[31,48–50] Similarly, closer and more frequent refill options for LPG increase its use,[34] and interruptions to supply chains can cause reversions to polluting fuel use, raising pollution exposures if only used during gaps between refills.[51,52] Having a second cylinder on hand can reduce this gap, but requires a higher upfront investment.[53,54]

The transition to clean energy can also depend on individuals' knowledge, perceptions, and trust in the technology and its potential benefits. However, interventions to increase users' perceived value of clean energy through changes in knowledge or attitudes have yielded only modest gains (if any) in its adoption and use.[30,55–59] Furthermore, long-term health outcomes might carry little weight, particularly for women, who might be more likely to face the immediate pressures of putting food on the table. Preferences alone are rarely decisive; their influence is shaped by economic, social, and institutional factors.

Pervasive gender inequities—where women face reduced agency and empowerment across psychological, social, and political dimensions—can restrict energy access[60] and therefore increase the health burden they face. Women disproportionately bear the negative health, time, and labour impacts of polluting fuel use,[61,62] as traditional gender roles often position them as the primary energy users within households. However, they also often have the least ability to access clean energy.[2] In addition, women might not have control over their households' financial resources, perpetuating their reliance on polluting fuels and prolonging exposure.[63,64]

Economic and non-economic factors are likely to interact in shaping energy choices, often in ways that can reinforce existing inequalities. Inconsistent availability and high costs of clean fuels drive fuel rationing, where households reserve clean fuels for specific tasks while relying on polluting alternatives to meet their remaining needs. Evidence from a multisite randomised controlled trial on four continents indicates that, when LPG is provided at no cost and is reliably available, near-exclusive use becomes the norm.[65] This result highlights that economic constraints—rather than behavioural or informational ones—are the primary determinants of fuel choices. Similarly, widespread reliance on electricity for diverse applications in wealthier regions could implicitly reflect how reliable and affordable access can yield its exclusive use.

Using policy to expand clean energy access and use

Large national policies have driven the greatest shifts towards clean energy by reducing the upfront costs of stoves that use clean fuels or electricity grid connections. By far the largest of such programmes have been implemented in India. In 2016, Pradhan Mantri Ujjwala Yojana (PMUY) expanded LPG access to 95·6 million women living below the poverty line, raising LPG adoption nationwide from 51% in 2016, to 89% in 2022.[16,66] However, actual consumption remains low among PMUY beneficiaries,[21,67] largely because of high fuel costs: each 14·2 kg LPG cylinder refill accounts for between 6% and 10% of monthly household expenditures.[68] Across the country, most PMUY beneficiaries purchase only three refills annually, despite being eligible for up to 12 subsidised refills.[69] Nevertheless, evidence from India around the time the scheme was launched indicates that exclusive LPG use can achieve large reductions in personal exposure to $PM_{2.5}$.[70] Similarly, the Saubhagya programme, which was launched in 2017 with the goal of providing electricity connections to all unconnected rural and poor urban households in India, extended connections to 25 million homes in 2 years.[71] However, millions remained excluded due to unaffordable access fees, and even those connected often faced high costs and unreliable, low-quality service that restricted its meaningful use. Although large-scale policies can rapidly expand access, ensuring affordability and reliability is essential in reducing long-term pollution exposure.

Government efforts to reduce the price of clean fuels have also driven substantial progress. Indonesia's kerosene-to-LPG transition is one example. In the early 2000s, 90% of Indonesian households used subsidised kerosene (a polluting fuel) for cooking. At the time, kerosene subsidies accounted for 9–18% of total state expenditures.[69] In 2007, the Government redirected subsidies for kerosene to LPG, providing users with an LPG stove, cylinder, and regulator for free in areas where kerosene use exceeded 40%.[22] The policy led to 86 million people switching to LPG over 4 years. Quasi-experimental evaluations of the policy found benefits to women's health, paid work hours,[72] and infant health. The LPG programme decreased infant mortality by 16–34% and low birthweight prevalence by 8–25% through decreasing exposure to household air pollution.[22,73] Although the programme successfully expanded LPG access and use, it has also necessitated substantial and ongoing state expenditures.[69] The Indonesian Government has increasingly digitised and targeted the subsidy for the poorest 40% of the population.

LPG subsidies in Latin America offer parallel experiences. Universal LPG subsidies in countries such as Venezuela, Ecuador, and Bolivia have dramatically reduced polluting biomass use for cooking.[74] Ecuador's subsidy has been instrumental in achieving near-universal LPG adoption for cooking, as a 15 kg LPG cylinder costs about US$2·50 (or 0·2–0·7% of monthly household expenditure).[75] However, these subsidies can also be large fiscal burdens for governments, and efforts to remove or reform them can be politically costly.[74–76] In response, Ecuador has promoted induction cooking as a strategy to ease the fiscal burden of subsidising imported LPG tied to global oil prices. An evaluation found increased household electricity consumption, decreased LPG consumption (and subsidy outlays), reduced net greenhouse gas emissions from cooking, and health benefits: a 0·74% decline in all-cause hospitalisations from each additional percentage point of canton-level induction stove use.[77] This type of transition programme might alleviate burdensome and volatile LPG subsidies, whereas targeted subsidies in countries such as El Salvador and Peru might provide a more fiscally sustainable model through private and public partnerships,[78] aiming to reach low-income households while also reducing the overall budgetary impact.

Tiered or block pricing schemes are widely used to enhance fuel affordability. In Ghana, utilities offer a basic amount of electricity at subsidised rates, and in South Africa, low-income households receive free basic electricity. However, these schemes can be regressive. In practice, wealthier, high-consuming households might capture most of the benefits, whereas low-income households sharing a single meter face higher effective prices—and the poorest, without any connection, are left out.[79]

Some policies have taken a more integrated approach, coupling clean fuel subsidies with measures designed to discourage the use of polluting fuels. In 2015, China's simultaneous ban of coal and subsidy for household electric or gas heating drove progress in expanding electric and gas heating and reduced the incidence of acute myocardial infarction by 7%, with greater impacts for women and older adults and in areas where the policy had been in place for more than 2 years.[80] These results indicate that polluting fuel bans can have beneficial effects on cardiovascular health if implemented successfully. By contrast, charcoal bans across east Africa were less successful due to weak enforcement.[81]

Beyond pricing strategies, some governments are expanding energy infrastructure and strengthening supply chains to boost access to clean energy. In China and the Philippines, among other countries, efforts are underway to extend the grid to rural and remote areas; meanwhile, electricity coverage is being expanded though mini-grid systems in Keyna and solar home systems in Bangladesh. Supported by bilateral arrangements and multilateral initiatives, these policies aim to cover part of the cost of extending the grid to specific homes or connecting them to decentralised systems. Although grid-related infrastructure tends to expand with rising demand, deliberate investments might be needed to accelerate progress. For electric cooking to scale up, grids should also be modernised to ensure sufficient capacity and reliability, especially during typical cooking hours.

Linking the definition, measurement, and tracking of energy access and use to health

Existing metrics and their limitations

Policy makers back clean fuels for many aims—health, climate, energy security, women's welfare, and, sometimes, to curb local environmental degradation. Causal evidence that clean fuels reduce household air pollution is strong;[15,70,82] evidence of health gains is somewhat weaker.[83] Although existing policies have rarely hinged on evidence of health gains, documenting those benefits matters for welfare analysis, targeting and design of future interventions, and for continuation of existing programmes and establishing policies in other countries. However, generating rigorous causal evidence is challenging, even in settings where clean fuel use has expanded. A major barrier in translating energy policy into health gains lies in how energy access is defined and measured.

Progress on access to modern energy is tracked mostly through SDG 7's metrics: the percentages of the population having access to electricity (indicator 7.1.1) and to clean cooking technology (indicator 7.1.2). Although these indicators command a great deal of policy attention, they miss important details of household energy use such as task-specific energy demands; consumption patterns that fluctuate with cost, accessibility, reliability, and personal preferences; and, importantly, the health risks linked to polluting fuel use or the potential health benefits of clean fuels.

SDG 7's simplicity is part of its appeal—electricity connections and reported use of clean fuels are easy to track. However, these measures do not reveal whether individuals have abandoned polluting fuels. If a clean fuel does not consistently meet all needs—due to price, reliability, or quality issues—users will continue to use polluting fuels in parallel to clean fuels to meet all their energy needs (a practice known as fuel stacking). This persistent use of polluting fuels drives air pollution exposure and health risks, as studies suggest that near-exclusive clean fuel use is needed to sufficiently reduce pollution exposures to improve health outcomes.[15,84] Consequently, relying solely on SDG 7's indicators could overstate the health benefits of clean energy by ignoring secondary polluting fuel use.

To bridge these gaps, researchers and policy makers have proposed more multidimensional frameworks. Some, such as the International Energy Agency (IEA)'s basic electricity access threshold and the Modern Energy Minimum, define minimum service levels for electricity. Others focus on aggregate measures of affordability, such as the Energy Intensity metric (ie, energy use per unit of gross domestic product) and the Energy Poverty Expense Share (the proportion of household income spent on energy). Although these approaches are useful for global benchmarking and are easy to implement, they say little about energy reliability, quality, or health impacts.

	Key outcome	Measurement approach	Broad coverage and global alignment?	Ease of data collection	Comprehensive analysis?	Reliability and quality considerations?	User or capability focused?	Focused on supply-side metrics?	Metric has a health component	Key citation
SDG 7.1a (electricity access)	Proportion of population with access to electricity	Binary measure based on household and Census surveys compiled by the World Bank and IEA; aggregated to regional or national scale	Yes	Yes	No	No	No	No	No	IEA (2025)[6]
SDG 7.1b (clean fuel access)	Proportion of population relying primarily on clean fuels and technology for cooking	Binary measure based on primary cooking fuel reported in household surveys compiled by WHO; aggregated to regional or national scale	Yes	Yes	No	No	No	No	No	IEA (2025)[6]
Energy Sector Management Assistance Program's Multi-Tier Framework	Classification of electricity and cooking energy access into higher and lower quality tiers based on service attributes	Household surveys capturing capacity, duration, reliability, quality, affordability, legality, health, and safety; assigns tier levels from 0 (no access) to 5 (full access)	Yes	No	Yes	Yes	Yes	Yes	Yes	Angelou and Bhatia (2015)[2]
IEA's Basic Electricity Access Threshold	Establishes a minimum standard for basic electricity services	Sets a minimum consumption threshold of 250–500 kWh/household per year to cover basic needs (eg, lighting and phone charging)	Yes	Yes	No	No	No	No	No	IEA (2020)[87]
Energy for Growth Hub's Modern Energy Minimum	Establishes a higher minimum standard for basic electricity services	Recommends a minimum consumption of 1000 kWh/household per year to support a modern standard of living	Yes	Yes	No	No	Yes	Yes	No	Kincer et al (2021)[88]
Multidimensional Energy Poverty Index	Assesses energy poverty based on deprivations in multiple energy services	Evaluates access to key energy services (ie, lighting, clean cooking, heating, refrigeration, entertainment, education, and communication); aggregates deprivations into an index score	Yes	No	Yes	No	Yes	No	Yes	Nussbaumer et al (2012)[89]
Total Energy Access	Establishes minimum standards for a comprehensive set of household energy services	Uses the Energy Supply Index to evaluate fuel type, appliance availability, and grid reliability; assesses six energy services including cooking, lighting, and heating	Yes	No	Yes	Yes	Yes	Yes	No	Practical Action (2018)[90]
Energy Poverty Expense Share (conventional affordability ratio)	Highlights the affordability aspect of energy access by measuring financial burden	Calculates the proportion of household income spent on energy costs, including fuel and potential appliance expenses	No	Yes	No	No	Yes	No	No	Boardman (1991)[91]
Energy Intensity	Measures energy consumption relative to output or area	Calculates energy use per unit of output (eg, gross domestic product) or per square metre of residential space; often disaggregated by end-use sectors	No	Yes	No	No	No	Yes	No	Ang (1994)[92]

IEA=International Energy Agency. SDG=Sustainable Development Goal.

***Table:* Summary of select energy access metrics and measurement approaches**

More comprehensive tools, such as the Total Energy Access framework, Multidimensional Energy Poverty Index, and Energy Sector Management Assistance Program's Multi-Tier Framework, go further. The Total Energy Access framework sets minimum service standards across six energy needs (ie, lighting, cooking, water heating, space heating, cooling, and information and communications), and considers fuels, appliances, and reliability. The Multidimensional Energy Poverty Index measures deprivation across lighting, cooking, heating, refrigeration, entertainment, education, and communication. The Multi-Tier Framework is perhaps the most detailed, capturing capacity, duration, reliability, quality, affordability, legality, and safety, and is the only framework to explicitly include health.

However, even these frameworks have limitations. Few account for the gendered dimensions of energy, including the specific energy needs of women or the outsized health and time burdens imposed on them by traditional fuels.[85,86] Moreover, these frameworks are often static, relying on cross-sectional data that do not capture how energy use shifts over time. And because they require detailed surveys, they have only been implemented in a handful of countries (eg, Kenya and Cambodia; table). In practice, only SDG 7 and IEA metrics have achieved global coverage.

Measuring what matters: data for tracking energy access, use, and health

Robust methods for accurately tracking energy access and use are essential to inform metrics and frameworks and design effective policies. Household surveys, such as national censuses or Demographic and Health Surveys, provide a valuable—if broad—snapshot of clean energy access by collecting self-reported information on electricity connections; primary fuels for cooking, lighting, heating; and, sometimes, fuel expenditures. When appropriately weighted, these surveys yield useful national and regional statistics—such as the percentage of households with access to grid electricity—but they miss important details, including secondary fuel use, service quality, and changes in use over time.

To better understand how energy is used by individuals and communities, and to inform more comprehensive frameworks, more granular data are needed. Utility records, satellite imagery, smart meters, and repeated phone surveys can capture spatial and temporal variations in energy use and can characterise task-specific and appliance-specific consumption patterns that are missed by traditional surveys. For instance, utility-based household electricity consumption data, reported at the subnational level, can reveal consumption inequalities, and night-time satellite imagery offers high-resolution views into the penetration and intensity of electrification progress.[93] Smart meters and sensors go further by tracking appliance-specific consumption, documenting not just whether an appliance is in use, but also the duration and intensity of that use.

These diverse data sources can be integrated into innovative new frameworks or improve current frameworks, to capture energy's broader role in health, livelihoods, and equity. In Honduras, for example, Pakhtigian and colleagues proposed the Energy Access Dividend framework and modelled benefits for Honduras across different electrification levels.[94] For these innovative approaches to inform policy, stakeholders should prioritise these data to link energy access to public health.

However, advanced approaches and more comprehensive frameworks are resource intensive; require well integrated infrastructure to automatically generate, analyse, and share data; and pose challenges around data standardisation and privacy concerns.[95–98] Effective measurement, therefore, must balance completeness and accuracy with practical constraints such as cost and data availability.

Another shortcoming of most measures and frameworks is their focus on a narrow set of services—primarily cooking, lighting, and heating. Essential functions such as food storage, cooling, health-care technologies, transportation, water heating, water treatment, productive uses (eg, irrigation, agroprocessing, and communication), and labour-saving appliances such as washing machines, are under-represented in current data systems. This gap is particularly evident in regions such as South America, south Asia, and sub-Saharan Africa, and becomes increasingly important as economic development and climate change reshape energy demand.[99] Without accounting for these services, we risk underestimating both energy needs and the associated impacts on health and wellbeing.

Ambiguity over how to track energy access and reliance on basic SDG 7 indicators leave policy makers without data on key aspects of energy transitions, including use, reliability, and affordability. As a result, the true pattern of energy use and its health impacts remains hidden, making it harder to develop solutions that curb the harms of polluting fuels.

Ultimately, the choice of measurement tools should reflect the goals of policy makers, practitioners, and researchers. Although resource constraints are real, linking energy access and use to health requires more meaningful metrics and more comprehensive data. SDG 7 could be expanded in several low-cost, high-impact ways. For instance, the electricity metric could categorise higher tiers of usage, and the clean cooking indicator could reflect exclusive use of fuels that meet WHO air quality guidelines and indicate a low risk of household exposure. Submetrics could include measures of affordability, such as the energy poverty expense share. These refinements could be implemented using existing instruments, such as Demographic and Health Surveys or national budget surveys, with additional disaggregation

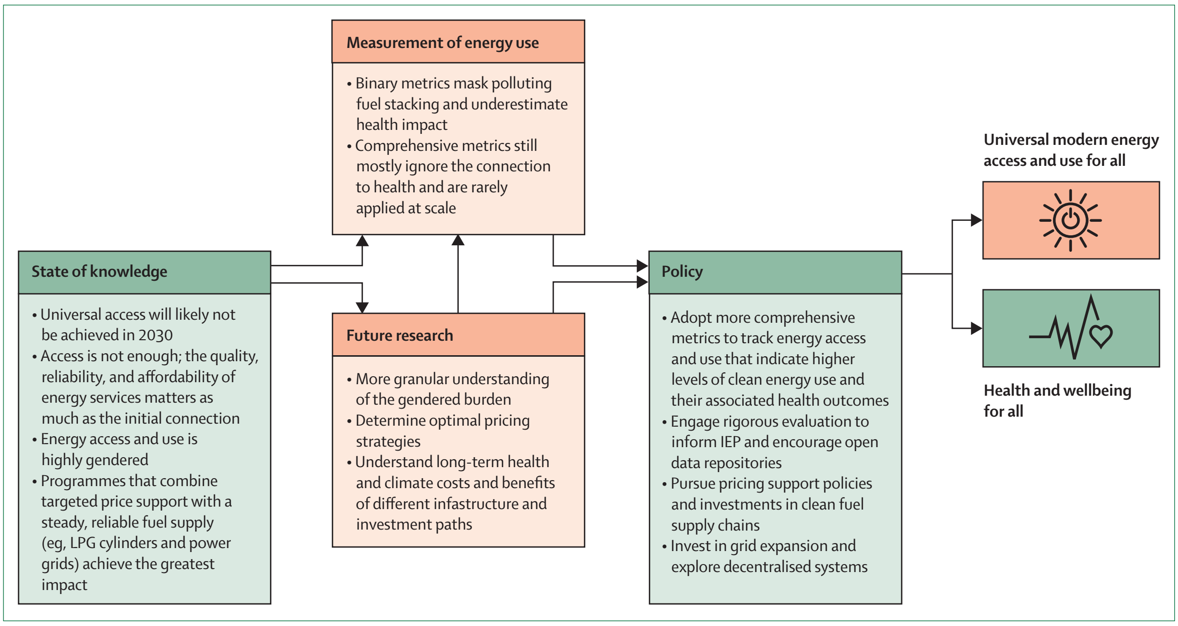

Figure 3: **Proposed research and policy agenda based on existing state of knowledge and limitations in current metrics for energy access and use**
IEP=Integrated Energy Planning. LPG=liquid petroleum gas.

by gender and location for within-country variation and, where feasible, time-use data for all household members.[12,100]

Global coordination among multilateral agencies and governments could elevate these metrics without requiring the full resource demands of, for example, the Energy Sector Management Assistance Program Multi-Tier Framework. Where resources allow, more granular data collection should be paired with open data policies to enable improved understanding of energy use patterns and inform more equitable, evidence-based transitions.

Charting the path forward

Expanding electricity and clean cooking is not just about technology or infrastructure; it also requires aligning incentives across governments, markets, and individuals to foster a transition that is efficient, affordable, and equitable. Here, we outline areas where collaborations between researchers and these actors can support partnerships that build on existing knowledge, provide better tracking of energy access and use, and generate new evidence to support policies across local, national, and international scales that achieve clean energy for all and improve health outcomes (figure 3). Meaningful progress requires an approach that accounts for the political, social, and behavioural complexities that shape energy access and use, while balancing incentives and costs to build sustainable and resilient systems that can withstand both local constraints and global shocks.

Integrated Energy Planning (IEP) has emerged as a core framework for guiding national energy strategies, incorporating supply-demand assessments, technology comparisons, and socioeconomic evaluations to outline sustainable pathways. Historically centred on electricity system planning, IEP is now being extended to planning future clean cooking transitions, and emphasises the need for cross-sector coordination and national oversight to address both energy and health priorities.[101,102] However, many low-income countries face barriers to implementing IEP effectively due to resource constraints, weakened institutional capacity, and political pressures. International guidance—such as that from the World Bank, the UN, or the IEA—might be able to bridge these institutional gaps, building capacity, standardising data collection, and developing adaptable models for local contexts.[101,102]

Researchers contribute essential tools and evidence to support IEP. Cost–benefit analysis is a key approach for quantifying the public and private costs of infrastructure and technologies, and for valuing the health and climate benefits of clean energy transitions. The Benefits of Action to Reduce Household Air Pollution model identified that shifting to clean cooking solutions, rather than interim, less efficient technologies (eg, improved biomass stoves), could yield net benefits of $1·4 trillion for 120 LMICs between 2020 and 2050.[103,104] Meanwhile, cost-effectiveness analysis offers a simpler and more targeted approach for comparing the costs of specific technologies relative to specific outcomes achieved, such as air pollution reductions with different stoves,[105] fuel savings,[106] or model of electricity extension (ie, grid *vs* off-grid).[107] Both approaches, however, depend heavily on high-quality data. Although evidence on the health benefits of electrification,[31,49] clean cooking,[108–110] and the modelled climate and health impacts of cleaner fuels[4] is growing, more work is needed to refine costs and model predictions, especially to address inequity across settings, gender, and incomes. Evidence is particularly scarce in rural and remote communities, and informal settlements where clean energy transitions are likely to be most challenging.

Moreover, research often adopts the idyllic perspective of implementing optimal policies over time, which is removed from a political reality characterised by unstable institutions and unpredictable behavioural responses. In practice, energy policies are shaped by electoral cycles, lobbying, and shifting administrations, which all steer policy towards immediate, visible gains at the expense of long-term investments in sustainable systems. This tendency becomes particularly problematic when considering the financial costs of universal clean energy access: Das and colleagues estimate that governments will face $598 million annually in administrative and programme costs to implement policies targeting universal clean cooking by 2050.[103] Although these costs are considerably less than their expected benefits, they nonetheless represent a massive sum, especially for under-resourced governments. Electrification is similarly expensive, requiring substantial investments in grid expansion or off-grid solutions, and increased generation and transmission capacity.[5,111]

Realising solutions for the path forward

Despite substantial progress in expanding clean energy worldwide, partnerships among policy makers, researchers, and practitioners must still overcome core challenges—chief among them are affordability and technology choice. Affordability remains a formidable barrier, prompting a host of policy experiments, ranging from subsidies and financing mechanisms to innovative models, such as digital payment systems, pay-as-you-go arrangements, and savings schemes.[31,55,112–115] Market-driven innovations—such as energy-as-a-service, where users can buy fuel as a subscription—show promise, but without adequate support structures to ensure that they reach people on low income, they risk reinforcing existing inequalities.

Decentralised solutions, such as mini-grids and solar home systems, are often touted as adaptable and affordable for remote areas and informal settlements.[116,117] However, despite considerable investments, the broader economic and health impacts of these models and their scalability remain understudied. Without rigorous evaluation, these solutions can fall short of delivering the long-term durability required for sustainable change.

Moreover, energy policy must contend with path dependence. For instance, promoting gas as a so-called bridge fuel might deliver short-term benefits to health and climate but risks committing to infrastructure that delays a transition to cleaner electricity. Policy makers should balance these trade-offs: although gas can provide immediate relief for the most marginalised populations, it might hinder progress on long-term energy goals.

Translating clean energy access into measurable gains in health and economic wellbeing will require more than intuitive policy prescriptions. Adaptive policies that offer gradual improvements and maintain flexibility could be required to deliver immediate welfare gains without compromising long-term clean energy goals. Granular, publicly available data and rigorous experimental methods are needed to identify the impacts of local solutions and guide effective policies.

Financing the path forward

Clean energy access remains underfunded. According to the IEA, at least $170–275 billion is required to close the electrification gap, yet even this would only provide restricted services (eg, lighting and phone charging for a couple of hours a day).[6] Up to $4·2–4·5 trillion per year would be needed to do so while limiting global warming to 1·5°C.[6] Meanwhile, clean cooking transitions require an additional $4·5 billion annually through to 2030, alongside $100 billion annually for recurring fuel costs, a burden that largely falls on users.[118] Despite these financial needs, annual funding in this sector averages just $130 million, with much of it directed towards so-called improved biomass cookstoves that fail to meet WHO health standards.[119]

Meeting these financial goals is achievable but will require strong political institutions capable of aligning short-term gains with long-term commitments. Clean cooking should be incorporated into integrated energy planning to streamline infrastructure. Decentralised electrification solutions can offer faster and more cost-effective options for remote and underserved communities than full grid expansion, but require substantial upfront investments and evaluation to ensure their scalability, reliability, and durability. Unreliable energy access also undermines economic productivity: frequent outages lead to substantial revenue and efficiency losses for businesses.[45,120] For households, energy reliability is equally essential; cooks will only fully adopt clean fuels if they trust these systems to be affordable, consistently available, and capable of meeting their daily needs.

International funding mechanisms, such as the UN's Clean Development Mechanism and the upcoming Sustainable Development Mechanism, offer opportunities to support clean energy initiatives. Carbon finance is also expanding rapidly through voluntary carbon markets and Article 6 of the Paris Agreement, which offers Internationally Transferred Mitigation Outcomes, with cookstove projects becoming one of the fastest-growing categories.[121] However, poor transparency, accountability, and quality concerns across various project types threaten the credibility of carbon financing,[122–124] and are also prompting re-evaluation of current methodologies and oversight. Strengthening carbon accounting approaches, increasing transparency, and ensuring equitable distribution of funds are essential to making these mechanisms reliable and sustainable sources of support.

Conclusion

We are far from achieving SDG 7's targets for universal access to electrification and primary reliance on clean cooking fuels—and even further from delivering the energy services needed to sustain long-term health benefits. Simply providing a clean cookstove or an electricity connection that powers a lightbulb is insufficient. In high-income settings, individuals rely on a diverse clean energy stack of affordable, reliable, and safe appliances—including electric stoves, microwaves, space heaters, and air conditioners—to meet their needs. By contrast, many in LMICs lack access to such a suite of clean energy services, forcing continued reliance on polluting fuels.

Policy must move beyond merely expanding access to clean energy, to creating the conditions necessary for near-exclusive use by addressing fuel affordability, reliability, and quality. Energy transitions should reflect the realities of the most vulnerable regions—where poverty and remoteness exacerbate challenges—and explicitly tackle the gendered dimensions of energy poverty. Researchers, in turn, should develop refined metrics at subnational levels that capture not only energy access but also reliability, quality, and equity, thereby generating an evidence base for informed decision making at local and global scales.

Energy transitions are not merely technical challenges—they are profound social, economic, and institutional endeavours with far-reaching implications for public and global health. To meet these challenges, we need comprehensive, evidence-driven, and politically grounded approaches that align diverse stakeholders, leverage resources effectively, and ensure that clean energy transitions deliver lasting and equitable health benefits for all.

Contributors

AG-W, CFG, and DK were responsible for the conceptualisation. AG-W, CFG, MJ, AP, SP, RS, KT, DWJ, ML, SB, LHK, and DK wrote the original draft and contributed to review and editing.

Declaration of interests

We declare no competing interests.

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