Title
Affordable Energy for Humanity: A Global Movement to Support Universal Clean Energy Access

Journal
Proceedings of the IEEE, 107(9)

ISSN
0018-9219

Authors
Nathwani, Jatin
Kammen, Daniel M

Publication Date
2019-09-01

DOI
10.1109/jproc.2019.2918758

Peer reviewed

INVITED PAPER

Affordable Energy for Humanity: A Global Movement to Support Universal Clean Energy Access

By JATIN NATHWANI AND DANIEL M. KAMMEN

ABSTRACT | Bold actions are necessary to unlock the potential for economic empowerment by eradicating energy poverty (UN Sustainable Development Goal 7) by 2030. This will require a sustained commitment to significant levels of new investments. Delivering on the promise of universal energy access and improved life quality has eluded policy-makers and governments over the past seven decades. Affordability of energy services for every global citizen, spanning vastly diverse regions and local contexts, requires the development and massive diffusion of technologies that offer "point-of-use" options combined with new business models. Social innovations and flexible governance approaches will also need to be integrated with technological advances. The scope and scale of developmental change span large-scale grid systems to decentralized distributed resources at community levels to the households. We recommend a global network of "energy access innovation centers" dedicated to providing a dynamic "extension service" that bolsters the entire supply chain of talent and expertise, design and operational requirements of system deployment and capacity to embed low-cost, high-performance next-generation technological solutions in the field. To meet the needs of those at the base of the economic and social pyramid, the dual challenges of economic development and transition to a low-carbon energy future make clean energy access the quintessential challenge of the 21st century.

KEYWORDS | Affordable electricity; clean technology innovation; energy poverty; life quality; social value creation; universal energy access

I. CONTEXT

The estimated investment required globally to achieve universal energy access is in the order of \$0.5–\$1 trillion or an annual investment of \$50 billion [1]–[3]. For one billion people at the base of the economic pyramid with no access at all, or highly deficient services, this translates into an investment commitment of \$50 per person annually until 2030. Investment on this scale can be meaningfully conceived, but its deployment can only be made possible through an intense focus on governance, business model innovations, and assurance that the specific solutions proposed are informed by the best scientific and technical knowledge available in the support decision quality that meets the highest standards of transparency and efficiency.

In this paper, we will explore the diverse pathways to universal access. Given the scale of change required and the need for urgent action [4]–[6], we focus on the need for coordination and direction of collective efforts through

Manuscript received September 9, 2018; revised March 11, 2019 and May 20, 2019; accepted May 21, 2019. The work of J. Nathwani was supported by the Ontario Council of Universities for the Ontario Research Chair in Public Policy for Sustainable Energy. *(Corresponding author: Jatin Nathwani.)*

J. Nathwani is with the Department of Management Science, University of Waterloo, Waterloo, ON N2L3G1, Canada, and also with the Waterloo Institute for Sustainable Energy, University of Waterloo, Waterloo, ON N2L3G1, Canada (e-mail: nathwani@uwaterloo.ca).

D. M. Kammen is with the University of California at Berkeley, Berkeley, CA 94720 USA.

Digital Object Identifier 10.1109/JPROC.2019.2918758

Fig. 1. ***Energy access as a multiplier of UN SDGs.***

a network of "energy access innovation centers" (EAICs) to address this global challenge. We describe the vision, objectives and outputs, program design and scale, key functions, and operational requirements for these EAICs. Notionally, the EAICs are similar to the regional research and outreach nodes of the Consultative Group for International Agricultural Research (CGIAR) and the enterprise development models of the World Bank's Climate Innovation Center (CIC). Core to this effort is the support for a coordinated yet distributed network focused on research, capacity building, and nurturing a new generation of entrepreneurs. The EAICs exemplify the need for and the value of "use-inspired basic research" to accelerate the development of energy access solutions on a global scale, with capacity building to create the next generation of leaders and change agents required for massive and rapid scale-up of successful pilots and local entrepreneurship as the fundamental delivery method of innovative solutions.

Ironically, the poor of the world—those who need access to energy the most—pay the most per unit of the energy service [4] based on fossil fuel resources. The premise of this paper—rooted in a desire to deliver affordable energy for humanity—responds to the urgent need for massive deployment of clean energy solutions that are scalable, available at low cost, and based on a sustainable supply of low-carbon energy sources. We believe that eradication of energy poverty with clean technology by 2030 (UN Sustainable Development Goal 7) will require accelerated access to existing energy systems with improved utilization of scarce assets. In addition, emergent innovations that can be characterized as "breakthrough solutions" will play an important role if designed as "fit-for-purpose" solutions for a diverse range of local and cultural contexts. The technological innovations when combined with new business models delivered by a new generation of entrepreneurs, small-to-medium enterprises (SMEs), and local change agents have the potential to yield maximum benefit to communities. The exploitation of synergies will remain a critical ingredient for success. If we are to take maximum advantage of the capacity for innovation that exists within university and industry research labs, there is a need to build stronger bridges between local implementers of solutions and global knowledge networks.

Energy poverty is a human development trap. Reliance on traditional fuels, such as firewood and kerosene, robs the energy poor of their greatest resource—time. Hours of time are spent every day collecting fuels, often by women and children. Reliance on fuels, such as kerosene, requires the ongoing purchase of fuel that becomes significantly costly over time while providing poor service. These fuels also cause significant adverse health effects from respiratory illness. Indoor air pollution related to indoor cooking using these fuels is a silent killer that claims approximately four million deaths annually, exceeding the toll of malaria and AIDS combined [7].

Our strategy for effective global change is to establish EAICs that bring into a sharp operational focus the ***creation*** and ***transfer*** of knowledge effectively and with urgency. The concept marks the transition from academic systems knowledge to practical implementation knowledge, based on robust and evidence-based empirical studies, direct feedback from end users, and deep engagement with communities to ensure adoption of solutions that meet the test of social and cultural acceptability.

II. CHALLENGE

A. Why Does Energy Access Matter?

As depicted in Fig. 1, energy access is a powerful multiplier of virtually all of the United Nations Sustainable Development Goals (SDGs). Energy services are intricately linked to the provision of adequate health and educational services that depend on a reliable infrastructure. Delivery of clean water and irrigation for agriculture, the capacity to transport produce to markets without spoilage, cooking with cleaner energy sources, reducing drudgery and burden on women for critical household tasks, and economic empowerment of individuals through labor-saving devices all rely on affordable energy services. Universal energy access is now within reach but requires rapid diffusion of clean energy options.

Energy access is defined by the International Energy Agency (IEA) as "a household having reliable and affordable access to both clean cooking facilities, and to electricity, which is enough to supply a bundle of energy services initially, and then an increasing level of electricity over time to reach the regional average" [2]. The "bundle of energy services" comprises a level of minimal energy requirements necessary for lighting and communication. Households without access to clean cooking facilities or the defined minimal level of energy services are living in energy poverty.

Energy access is one key pathway for the reduction of endemic global inequality, but it will require radical progress in the development of scientific and technological solutions that can deliver aggressive cost reductions without compromising quality and significant improvements

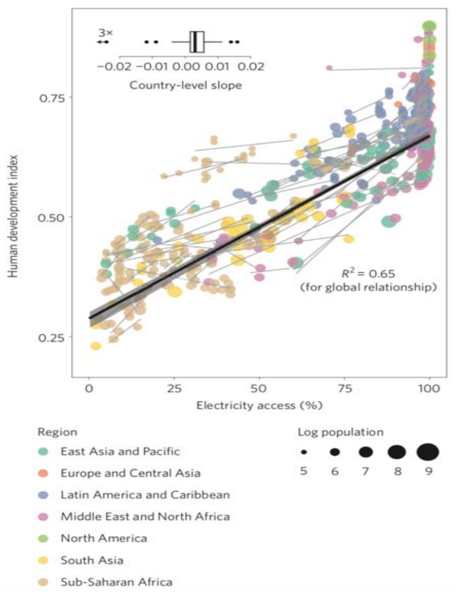

Fig. 2. ***Relationship between access to electricity and HDI for 2000–2010 [8].***

in performance. Low-cost energy becomes the driver of high-value impacts on life quality.

The value of energy can be observed through many lenses (see Fig. 2), but certainly a simple and dramatic summary is how strongly and clearly across regions it correlates with the quality of life indicators, such as the human development index (HDI) [8].

Globally, approximately 1–1.3 billion people are living without electricity. Lack of energy access is felt most acutely in the regions of Sub-Saharan Africa (SSA), where 62.5% of the population are without electricity, and Southeast Asia, where 20% of the population are without electricity. Globally, a stark energy divide also exists between urban and rural areas, with urban electrification at 97% compared to rural electrification at 76% [5]. Despite recent progress, mainly in developing Asia, population growth continues to outpace the electrification rates and future projections, as suggested by the IEA that by 2030, an estimated 670 million will still be without electricity [2].

In the poorest regions, notably in SSA, population growth is forecasted to outpace the current rate of the provision of new energy access, leading to a dramatically worsening situation over the upcoming decade [8]. The current pace of electrification via existing large-scale grid systems certainly has a role to play in expanding energy access, but the costs of new grid connections for many of the poor are too high and the reliability of the service is often the lowest [8].

An equally compelling rationale for low-cost clean energy solutions is the powerful role that the energy access plays, as an enabler of economic productivity, to help bring the disenfranchised into the mainstream economy, reducing migration pressures and conflict. Arguably, this is particularly significant in a world of climate risks: keeping people on their own lands will require higher energy inputs from clean energy sources. Whether it is life in a refugee camp or village frequented by unreliable patterns of rainfall, lack of affordable energy access becomes an impediment to agricultural productivity and income-generating opportunities. With no clear pathway out of poverty, migration pressures increase.

Gender inequity is another face of energy poverty. It manifests itself in the lives of young girls and women through hardship and difficult work. When precious time is stolen collecting fuelwood and water, options for education become vanishingly distant. The human dimension to the problem of energy access is as clear as it is disturbing—to condemn a vast proportion of humanity to a quality of life that is almost at par with living in the Stone Age. This is as much a stain on our collective conscience, as it is on our ability to marshal resources to solve this problem.

Fig. 4 shows the relationships of per capita electricity and selected human development indicators. Each data point is from a different country, with some nations represented multiple times, at different points in time [8].

In fact, extensive evidence exists that there are both the economic and social benefits of scaling up energy access. In a series of studies that have been repeated over time and as more data became available, a robust relationship between the electricity consumptions per capita emerged for a whole range of metrics of development has been explored (see Fig. 3). From literacy [see Fig. 3(a)], to educational attainment [Fig. 3(b)], to metrics of poverty

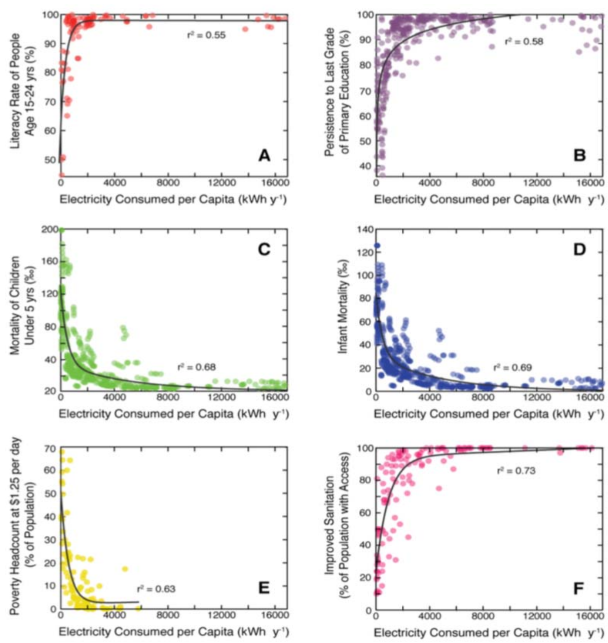

Fig. 3. ***Relationship between energy access and key metrics of development. Source: [8].***

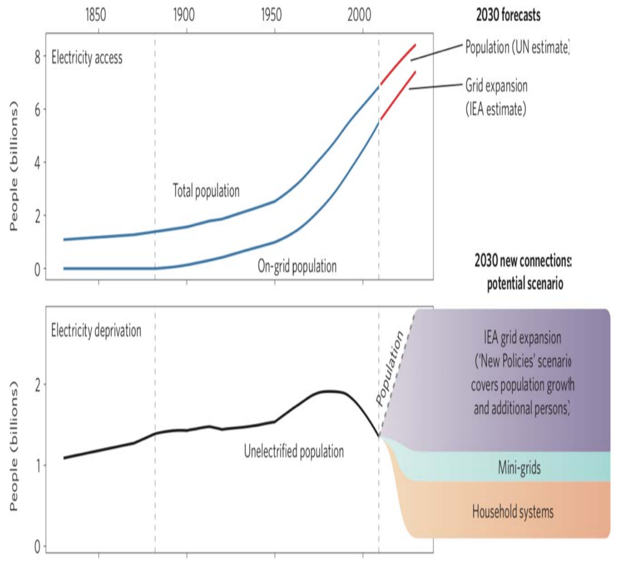

Fig. 4. *Two centuries of historical trends. Source: [8].*

alleviation, to gender equity, and to many others, we observe a clear correlation with increasing energy consumption.

These patterns show no causation but many clear correlations. In fact, the hyperbolic shape seen in each of the graphs tells a fascinating story. First, there is a characteristic linear phase, where improvements in the quality of life increase rapidly. This could be described as the "takeoff" phase, where increasing the resource availability correlates with improving services. Each of these linear phases, however, gives way to a flattening of the curve, where we observe little or no continued improvement.

Far from highlighting a plateau, this flat phase highlights the fact that a wide range of different energy resource inputs can be seen to correlate with comparable levels of service. These are complex relationships, to be sure, with a myriad of ways to provide similar levels of service. Overall, however, the lesson is that an investment in energy services enables a range of economic and social improvements that ripple across the economy. In our proposal, the EAICs will partner leading energy access research labs around the world with practitioners focused on these applications in a network that will make the investment all the more valuable and compelling for both the international community and, increasingly, the private sector.

If the energy poor are to be drawn into the mainstream of global economic well-being, then access to low-cost energy is a fundamental requirement. Energy poverty remains a barrier to economic well-being for such a large proportion of humanity that the rationale for action now is compelling. The importance of energy access has been recognized by several organizations, including the United Nation's Sustainable Energy 4 ALL (SE4ALL) Program, the World Energy Council, the World Bank, NGOs, and many charitable foundations. It is also comprehensively documented in the Global Energy Assessment [6]. Although progress, at the global level, has been tangible, it has been slow and not large enough, in scale and scope, to address the basic human needs of a large swathe of humanity. Massive diffusion of new technologies that can provide energy services at a much lower cost is the necessary building block to help make a difference in the lives of many that have a few needs.

To effect meaningful change, we need to marshal the vast intellectual capacity of humanity in order to address two of the most important challenges of the century—and to do so in concert. We must achieve a low-carbon energy system that also meets the requirement of affordable energy for all of humanity.

It is clear that universal energy access cannot be achieved without a major scientific and technical push to lower the costs by a very large margin, to improve reliability, again, by a large margin, and to find robust solutions that are scalable at the global level. Our primary focus is the scientific research and development of next-generation technologies that will yield large improvements in the overall performance of the existing energy systems.

III. POWERFUL SOLUTION: A MOVEMENT TO CREATE AN ''ENERGY ACCESS EXTENSION SERVICE FOR THE PLANET''

The urgency and transformative economic, social, and environmental benefits of making energy access a top-tier global priority means that we must focus coequally on knowledge creation, social and behavioral change, and both evolutionary and radical systems redesign.

The need for solutions that are not only economically but also environmentally sustainable makes the goal of affordable universal access to clean energy consistent with climate change goals but together poses a formidable challenge.

Our goal is to make energy poverty a footnote of history; we believe that if this problem receives the scientific, technical, financial, and social attention it deserves, energy poverty can be eradicated by 2030.

A. What Is Different About Our Solution?

Our solution mobilizes existing networks and resources in a novel way to address a complex challenge. Current global investments in meeting energy access goals are minimal, often summarized as "two light bulbs and a fan." Our aim is to develop long-term strategies that will lead, over time, to full access to modern energy services for improved life quality and economic self-sufficiency.

Current approaches focus narrowly on delivering "predetermined" technology solutions that focus on energy access in isolation to wider efforts to enable economic growth and gender equality. Our approach is based on both the recognition of the scale of the problem and the benefits of addressing it through an intensive, comprehensive, and coordinated global focus. The emphasis is on scientific, technological, and socially appropriate innovations that offer large and aggressive reductions in cost. We outline a number of the means to leverage social and business innovations to learn from and address "failures-in-the-field" and substitute them with 'best-practices' and solutions in a dynamic interaction between 'use-inspired' research and practice.

As we look at a full range of energy access options, it is clear that, however, one prioritizes on-grid, minigrids, or decentralized off-grid solutions, all will be part of a successful transition to universal access. Here, we lay this out in terms of both the gap between total people and those with access [see Fig. 4, top panel], and a rough estimate of the role that these different modalities will play (see Fig. 4).

Our challenge is to enable users of energy technologies for productive applications in ways that create tangible value for individuals, households, and communities. Thus, we emphasize the need for multiple social and organizational capacities to be built in conjunction with technology.

Our goal is to attend carefully to the design of ownership and reinvestment strategies with a focus on maximizing opportunities for local economic development and poverty eradication.

Evidence suggests grid extension, solely, is an inadequate answer to solve energy access problems for many rural and urban communities [14]–[16], and there is a need for a creative approach to the deployment of new, distributed energy technologies to enhance cost-effectiveness, reliability, and resilience of the energy system.

We focus on a meaningful integration of knowledge across several domains and design projects in an integrated manner from the outset to address multiple human and environmental outcomes.

B. What Will It Take?

For example, the World Bank's Access Investment Model provides the detailed bottom-up estimates of the cost of reaching universal access in countries with large electricity access deficits. These countries reflect differences in population and geography as well as local unit costs, and they can be used to give a global estimate of access investment needs [3]. The model, based on the multitier framework, allows users to choose the tier of access, which would be used to meet the universal access target, and illustrates how dramatically this affects the costs of electrification.

To reach universal access at Tier 5 (full 24×7 grid power) would require investments of $50 billion annually or $500 billion over ten years [1]. This is a high-level estimate that translates to a commitment at a level of $50 per person per year. Investments on this scale provides an anchor to a consideration of the level of funding appropriate to bring to fruition an operational concept of a global extension service linked to a network of EAICs.

IV. ENERGY ACCESS INNOVATION CENTERS

Our recommendation for the establishment of a linked network of EAICs as "global extension service" is similar to the CGIAR and the newer enterprise development models of the World Bank's CIC and the European Institute of Innovation and Technology's Knowledge Innovation Communities (KICs).

To establish a network, for example, each EAIC with a notional budget of $5 million per year over ten years would require a commitment in the order of $50 million per center or $250 million for five regional EAICs.

A "University Movement" dedicated to the creation of new knowledge and solutions specific to the eradication of energy poverty is one part of the puzzle. There is a growing need to fill the gap in the entire supply chain that supports knowledge creation, development and deployment of targeted solutions, and rapid feedback of corrective actions from lessons learned from failures.

We have seen a number of globally effective programs that have had a significant impact on addressing global challenges. The food crises and famines of the 1950s and 1960s led to the scale-up—with a modest initial investment—of a global food research and extension effort [12].

The EAIC model embodies energy services that essentially reproduce the best lessons from the global agricultural extension services of the CGIAR effort with the current energy and clean technology efforts that the CICs focus on supporting. The current CIC network provides an important operational network today that brings together technical, market, and social innovations with prospective entrepreneurs and community groups.

EAICs are places where change agents—aspiring entrepreneurs and leaders in the energy access sector—receive day-to-day support to assist them in developing solutions that will serve the regional market of their EAIC. The EAIC functions like a traditional incubator, in which it provides mentorship, financial, technical, and other advisory services and conducts regional market research for the benefit of the change agents that it hosts

A. Program Design

We describe, in the following, the key support functions of the EAIC's program design and highlight a few exemplars that provide the motivation to support a global movement in support of universal energy access. We highlight the role of research, capacity building, and entrepreneurship.

As a preliminary step, the most appropriate locations of EAICs—in light of compelling needs—would be three in Africa (South, East, and West Africa), one in Latin America, and one in Asia. Once operational, the renewal mandates of the EAICs and the establishment of the additional new EAICs can be evaluated on the basis of the experience and a successful assessment of the value of contributions to the advancement of the universal energy access.

Over time and building on successful outcomes, our goal is to make (EAICs) the hubs for infusing research contributions into programs that recruit and support promising entrepreneurs. This effort brings research directly to the needs of energy service goals and places the entrepreneurs in direct contact within partner institutions all over the world. This team-based approach will enable both the research and deployment/extension agents to develop projects that are codesigned with partners for radical improvements in the affordability of clean energy solutions in underdeveloped markets.

The key contribution of the EAICs is to deepen and support a supply chain of expert knowledge and research with outreach into a virtuous feedback loop that channels innovations and tailors them to local needs via locally supported community groups and entrepreneurs. This will augment and accelerate the existing efforts by state- and individual-owned utilities.

The EAICs are intricately linked to the local entrepreneurs who can access a global network of leading university research labs pursuing breakthrough innovations in clean energy technologies.

B. Research

The basic objective is to nurture and accelerate the "use-inspired basic research" for energy access on a global scale. To bridge the gap between leading research labs and impact-oriented organizations that work in the field, the research focus is to develop and test reliable and cost-effective strategies for reaching the goal of providing affordable, equitable, and clean access to energy supplies. Enhancing affordability through technological innovation is particularly important in meeting the needs of the most impoverished markets. For new technologies to be successful, they must be designed with a deep understanding of their use.

C. Capacity Building

Create the next generation of leaders and change agents to build the energy access sector for massive and rapid "scale-up" of solutions. Experiential learning opportunities—through fellowships—within a global network of partner institutions can provide a dedicated pipeline of professionals empowered to inform and shape global and local knowledge networks. EAICs become a hub for catalyzing solutions proposed by engineers, natural scientists, social science experts, economists, sociologists and anthropologists, innovators, and practitioners working in teams. With effective facilitation, the EAICs act as a clearinghouse for strategies that foster technological change, improve organizational capabilities, enable institutional support, and provide behavioral advice and training.

D. Entrepreneurship

The objective is to seed financially viable social enterprises through the EAICs, and the recruitment of talent becomes the pathway to support individuals who bring innovative solutions to the markets with deep local knowledge.

In terms of tangible outputs, we view new businesses and entrepreneurial ventures emerging out of the EAICs as a critical pathway for advancement out of energy poverty. EAICs can adapt and use the incubator model, based largely on the World Bank's Climate Innovation Centers. They provide working space, mentorship, and start-up support for those recruited into the program.

The next generation of change agents—who have benefitted from the EAICs—will have direct access to the leading-edge scientific knowledge emerging from university-based research labs and local knowledge networks of implementers at the regional level. The change agents are at the "work face" on specific projects to develop new solutions for energy poverty in their region. They become the entrepreneurs, policy influencers, innovators, and leaders desperately needed to grow the energy access sector at the pace and scale required to meet SDG 7.

An "extension service" for the benefit of implementers comprises the cutting-edge insights and innovations from the lab and communicate their relevance to field-based implementers. Innovation reports, crafted for regional relevance by the EAIC, with wider dissemination would shape the "state-of-the-art" scientific findings relevant for use and informed best practices.

"Use-inspired research" initiatives at leading universities globally can draw from the experience of the EAICs and disseminations of its outputs. The goal is to provide a tighter link between emerging research directions and key themes identified by EAICs. Through mechanisms, such as "Global Innovation Summits," the focus is on fostering knowledge-sharing opportunities between those working in the field and those working in the research labs. Summits will be the major global events, where leading innovations and entrepreneurial projects gain the attention of investors and decision-makers.

E. Scale

The funding for the EAICs will primarily support a strong fellowship program, infrastructure for the extension service, global summits, and research and implementation activities managed by the EAICs. The goal is to accelerate upstream research and downstream deployment of locally appropriate solutions.

With a notional annual budget for each EAIC at \$5 million per year, the EAICs can recruit and host up to 30 talented individuals per year through the fellowship program. With five EAICs operating at this level, the program can be envisaged at a level of capacity to produce 1500 change agents worldwide over a ten-year period—300 in each EAIC region.

Table 1 Consultative Group for International Agricultural Research (CGIAR)

Purpose and Relevance	Activities and Impact	Funding
Global scale extension service linking top research centers with a global network of implementers	15 CGIAR Research Centers implement collaborative large-scale CGIAR Research Programs (CRPs) conducted in more than 60 countries with the support of over 10,000 scientists and other staff	$1B per year
Conducts breakthrough discovery research, field data collection and delivery of solutions		Long-term funding primarily from national governments
Utilizes use-inspired basic research at research centers to deliver positive outcomes across relevant SDGs	Hundreds of partners, including national and regional research institutes, civil society organization, academia, development organizations and the private sector	Administered through a trust managed by the World Bank
Commitment to innovation and local entrepreneurship as divers of systems-level change in impoverished regions	For every $1 provided to CGIAR over its lifetime, the return on investments is evaluated at $17	

F. Knowledge Creation–Knowledge Transfer–Knowledge Use

The schematic shown in Fig. 5 highlights the need for the effective knowledge transfer from the global knowledge pool, the need for knowledge translation, and linkages to local knowledge through local implementation networks. In our view, there is a compelling need to learn rapidly from the failures in the field to shape future research directions and exploit the capacity of advanced research labs to create new solutions.

The EAIC, at its core, supports the transfer of knowledge between local and global knowledge networks in the program. The EAIC provides an extension service, benefitting local implementers, by working with university research labs to crystallize the latest science and innovations and help identify specific steps improve the operations of local implementers in their regional network. The EAIC develops and disseminates actionable knowledge that benefits change agents, as well as university researchers and the broader energy access sector.

The ultimate goal of the EAICs is to create a dynamic, information-rich environment with excellent support services that foster the development of new business models, social enterprises, and innovative market-serving solutions in the region, in which they operate.

EAICs are largely modeled on incubation hubs, such as the World Bank's Climate Innovation Centers that host local entrepreneurs in a number of countries across the developing world, enabling them to create climate-friendly businesses through recruiting local entrepreneurs and providing them with mentorship and a range of support services (see CIC business plans).

G. Exemplars

We draw upon three existing networks that provide an approach for meeting the challenges of bringing research, entrepreneurs, government agencies, civil society institutions, and diverse stakeholders to address the needs of the poor and under-served populations. A brief summary of several key attributes that provide high-level guidance for the establishment of EAICs is provided in Tables 1–3. This is neither an exhaustive or complete list nor does it describe fully the limitations of each of the networks and its past experience. However, they provide a basis for the next steps in the development of a detailed program design for an EAIC.

H. University Research Labs

Leading university research labs around the world are engaged in the research on the topic of energy access—from technology to data analysis and modeling to policy, finance, community engagement, and so on. These research groups span the natural and social sciences' spectrum. They house a wealth of knowledge, resources,

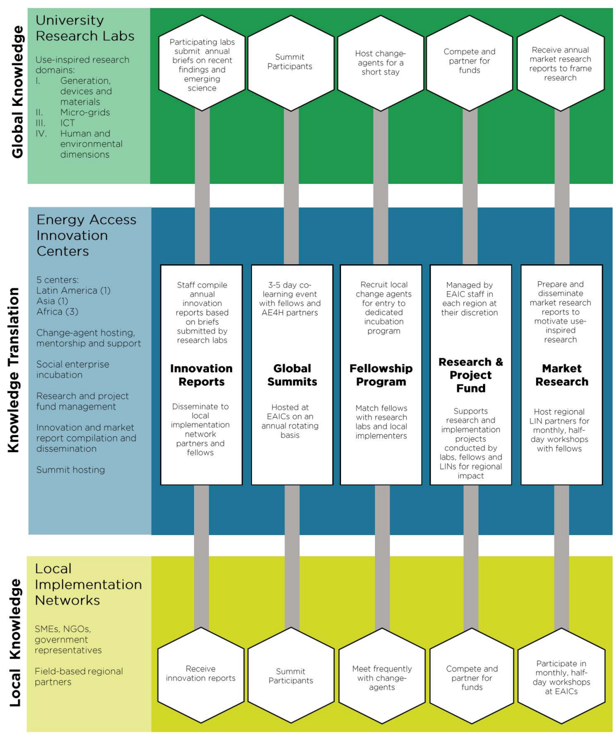

Fig. 5. ***From global knowledge to knowledge translation to the use of local knowledge.***

Table 2 World Bank/InfoDev CICs

Purpose and Relevance	Activities and Impact	Funding
Incubators provide start-up services to support climate relevant local entrepreneurship and innovation in a number of developing world countries (Ghana, Kenya, Ethiopia, Morocco, South Africa, India, Vietnam and the Caribbean) Co-located at partner institutes including universities with existing business support infrastructure and access to talent Climate technology, agribusiness and digital entrepreneurs that participate in the CIC programs are regionally-focussed change-agents	Each CIC has its own holistic and tailored approach to innovation developed through a local stakeholder engagement and business plan development process CICs offer services including: ▪ Proof of concept funding ▪ Access to early stage capital ▪ Access to technical facilities and technology information ▪ Mentorship and networking ▪ Business training and skill-building ▪ Policy advocacy ▪ Promoting internationalization opportunities Program is in start-up phase with business plans having been developed by each CIC	Each CIC has a budget of approx. $15-20M spread over 5 years Provided by The World Bank/infoDev in partnership with a number of national governments

Table 3 European Institute of Innovation and Technology—KICs

Purpose and Relevance	Activities and Impact	Funding
Partnership of leading research, private and public sector organizations in Europe to spur innovation and develop new enterprises for a sustainable economy Knowledge Innovation Communities (KICs) created across a range of topics including climate and energy support entrepreneurs to develop new ventures Partners and entrepreneurs given access to international knowledge network Each KIC has offices across Europe which develop local implementation networks (Climate-KIC, for example has 13 national centers)	A variety of programs integrate education, research, technology transfer and business creation A number student education initiatives on KIC themes (including 7 Masters programs in renewable energy run by InnoEnergy KIC) A range of business development services are offered for aspiring entrepreneurs and existing SMEs through each KIC Climate-KIC conducts 'Pathfinder' research projects to identify markets for climate technologies, followed by investment in market-serving solutions from existing businesses, new joint ventures and spin-off companies	€2.7B Horizon 2020 funding to establish European Institute for Innovation and Technology (2014-2020) €81.2M for Climate-KIC €77.5M for InnoEnergy-KIC

and capacity to develop new solutions, including those that can significantly reduce the costs of energy systems through breakthrough innovations. The scope and scale of research encompass the following areas of inquiry:

1) energy system modeling (on- and off-grid systems and integration);
2) island microgrid design;
3) frugal innovation and design in a developing world context;

i. Generation, devices and advanced materials
ii. Micro-grids for dispersed power
iii. ICT for energy system convergence
iv. Environmental and human dimensions of energy system transitions

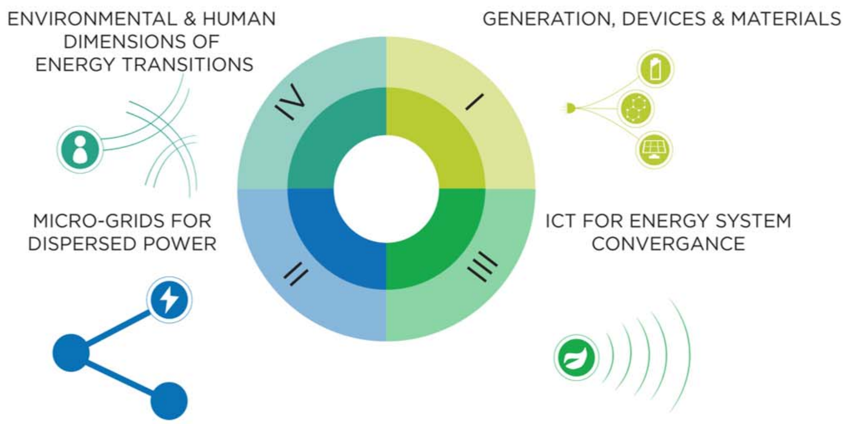

Fig. 6. ***Knowledge creation, integration, and dissemination across multiple disciplines.***

4) renewable energy basic science;
5) renewable energy systems' design and storage technologies;
6) social entrepreneurship/business model development;
7) energy policy, integrated system planning, and analysis relevant to the African, Asian, and Latin American contexts;
8) smart energy systems;
9) energy storage, power electronics, and devices;
10) big data analysis and the Internet of Things (IoT);
11) energy efficiency and role of "superefficient" appliances;
12) integrated water-energy cycle management;
13) ICT for energy systems;
14) microgrid/power systems design and modeling;
15) energy access and conflict in the developing world.

A key barrier often faced by these research centers is their remoteness from regions facing energy poverty. The EAICs program would, therefore, aim to provide a bridge between the field and the lab that enables use-inspired basic research on energy access through quick feedback loops between projects in the field and lab-based researchers.

Our objective in proposing the Global University Movement working with EAICs in support of universal energy access is to expand the scope and scale of activities for university-based researchers to collaborate actively in developing pathways and deliverables of projects worldwide but with an urgency to help eradicate energy poverty. We acknowledge the efforts of several institutions involved in this paper, including the UN SE4ALL, USAID, GIZ, Power 4 All, U.K. DFID and GCRF, IEA, and IRENA, among several others. Our goal is to bring university research labs working at the leading edge of new scientific discoveries and knowledge to bring to fruition innovative solutions relevant to the context of the energy poor and also help expand core areas of competencies and expertise to support field practices. Our aspirational goal is the full alignment of the global scientific knowledge base with an improvement of life quality through energy access.

Here, we have identified four domain areas of inquiry and focus for research shown in Fig. 6.

Participating university research labs, as a part of an extensive EAIC network across all regions of the world, can compile annual innovation briefs that outline the R&D advances and recent innovations on the horizon. These reports when integrated into a set of innovation reports tailored to the local contexts in each of the five regions can help spur rapid diffusion and deployment of new technologies to meet the challenges of affordable clean energy.

I. Extension Services

Agricultural extension—the transfer of knowledge from the front lines of scientific research and technological development to farmers and growers—has been a critical enabler of increased crop yields globally since the Second World War. The CGIAR agricultural extension services concept—with its limitations—still provides inspiration to find an approach quick feedback loop between advanced research labs and the farmer's field (lab-to-farm).

The EAIC program envisions creating a global extension service for energy access, where the focus is jointly on the science, the technology, and the practice of energy extension, with strong attention on feedback throughout the network for rapid diffusion of new knowledge to useful solutions as the face of work. It will deliver insights from university research labs and EAICs to local implementers, including SMEs, NGOs, policy-makers, and others on the front lines of energy poverty. Extension service is a multilayered set of activities that inform and shape the outcomes for a large number of actors and groups across the entire supply chain of energy access delivery.

V. CONCLUSION

We conclude that the challenge to meet the twin goals of meeting reduction targets for climate change and provision of universal energy access, affordable and accessible to a very large proportion of the global population, will require a massive investment, roughly estimated in the order of $50 billion per annum.

To ensure that investment on such a scale remains effective—in light of the rapid expansion of emerging knowledge—it requires a unique emphasis on matching new solutions with an in-depth understanding of the local context. The quintessential challenge is to create sustainable improvements to the quality of life without undermining the basis for investments.

We propose "A Global Movement to Support Universal Clean Energy Access" to be implemented through the establishment of five EAICs globally.

For clean distributed energy solutions to become a reality for those at the bottom of the pyramid, "Use-Inspired Basic Research" must inspire the development of the next generation of technologies and business models for adoption at the local level. The primary goal is to deliver on the promise of affordable access to energy services the affordability of off-grid solutions, where they are needed most and where they have the greatest potential for improving life quality. ■

REFERENCES

[1] *State of Electricity Access Report (SEAR)*, IBRD/WB, World Bank, Washington, DC, USA, 2017, p. 7.

[2] *Energy Access Outlook 2017-From Poverty to Prosperity, World Energy Outlook Special Report*, OECD/IEA, 2017.

[3] *Sustainable Energy for All 2017-Progress Towards Sustainable Energy*, IEA/World bank, Washington, DC, USA, 2017.

[4] *Electrifying Africa—Lights, Power, Action in Depth Follow-Up to APP Report—Power, People, Planet: Seizing Africa's Energy and Climate Opportunities*, Africa Progress Panel (APP), Geneva, Switzerland, 2017, p. 23

[5] *Power for all–Electricity Access Challenge in India*, State of Electricity Access Report (SEAR), World

Bank, Washington, DC, USA, 2018.
[6] IEA, *Financing Energy Access—International Energy Agency*. World Energy Outlook (WEO), 2011, Ch. 13, p. 469.
[7] WHO. (2016). *Factsheet, Household Air Pollution and Health*. [Online]. Available: http://www.who.int/mediacentre/factsheets/fs292/en/
[8] P. Alstone, D. Gershenson, and D. M. Kammen, "Decentralized energy systems for clean electricity access," *Nature Climate Change*, vol. 5, pp. 305–314, Mar. 2015. doi: 10.1038/NCLIMATE2512.
[9] C. E. Casillasm, and D. M. Kammen, "The energy-poverty-climate nexus," *Science*, vol. 330, pp. 1181–1182, Nov. 2010.
[10] *Towards a Sustainable Energy Future, Energy Access for Development*, Cambridge Univ. Press, Cambridge, U.K., 2012, ch. 19.
[11] M. Bazilian *et al.*, "Accelerating the global transformation to 21st century power systems," *Electr. J.*, vol. 26, no. 6, pp. 39–51, 2013. doi: 10.1016/j.tej.2013.06.005.
[12] M. R. Dove and D. Kammen, *Science, Society and the Environment: Applying Anthropology and Physics to Sustainability*. Boca Raton, FL USA: Taylor and Francis, 2015.
[13] D. Stokes, *Pasteur's Quadrant: Basic Science and Technological Innovation*. Brookings Inst. Press, 2011.
[14] S. C. Bhattacharyya, "Financing energy access and off-grid electrification: A review of status, options and challenges," *Renew. Sustain. Energy Rev.*, vol. 20, pp. 462–472, Apr. 2013. doi: 10.1016/j.rser.2012.12.008
[15] AFDB. (2017). *Green Mini-Grids Africa Strategy: Green Mini-Grids Market Development Program*. SEforAll Africa Hub and AFDB. Accessed: Jun. 29, 2017. [Online]. Available: http://greenminigrid.se4all-africa.org/uploads/gmg-africa-strategy.pdf
[16] *Poor Peoples Energy Outlook*, Practical Action, London, U.K., 2017.

ABOUT THE AUTHORS

Jatin Nathwani holds the prestigious Ontario Research Chair in Public Policy for Sustainable Energy and is currently a Professor cross-appointed to the Faculty of Engineering and Environment. He is also the Founding Executive Director of the Waterloo Institute for Sustainable Energy (WISE) and a Fellow with the Balsillie School of International Affairs (BSIA), University of Waterloo, Waterloo, ON, Canada. He has had 30 years of experience in the Canadian power sector as a Professional Engineer.

Daniel M. Kammen holds a dual appointment in the Energy and Resources Group, where he serves as the Chair of the Goldman School of Public Policy and directs the Center for Environmental Policy and the Department of Nuclear Engineering. He was the Director of the Transportation Sustainability Research Center, Richmond, CA, USA, from 2007 to 2015. He is currently a Distinguished Professor of Energy at the University of California at Berkeley, Berkeley, CA, USA, and a former Science Envoy for the State Department. He is also the Founding Director of the Renewable and Appropriate Energy Laboratory (RAEL).