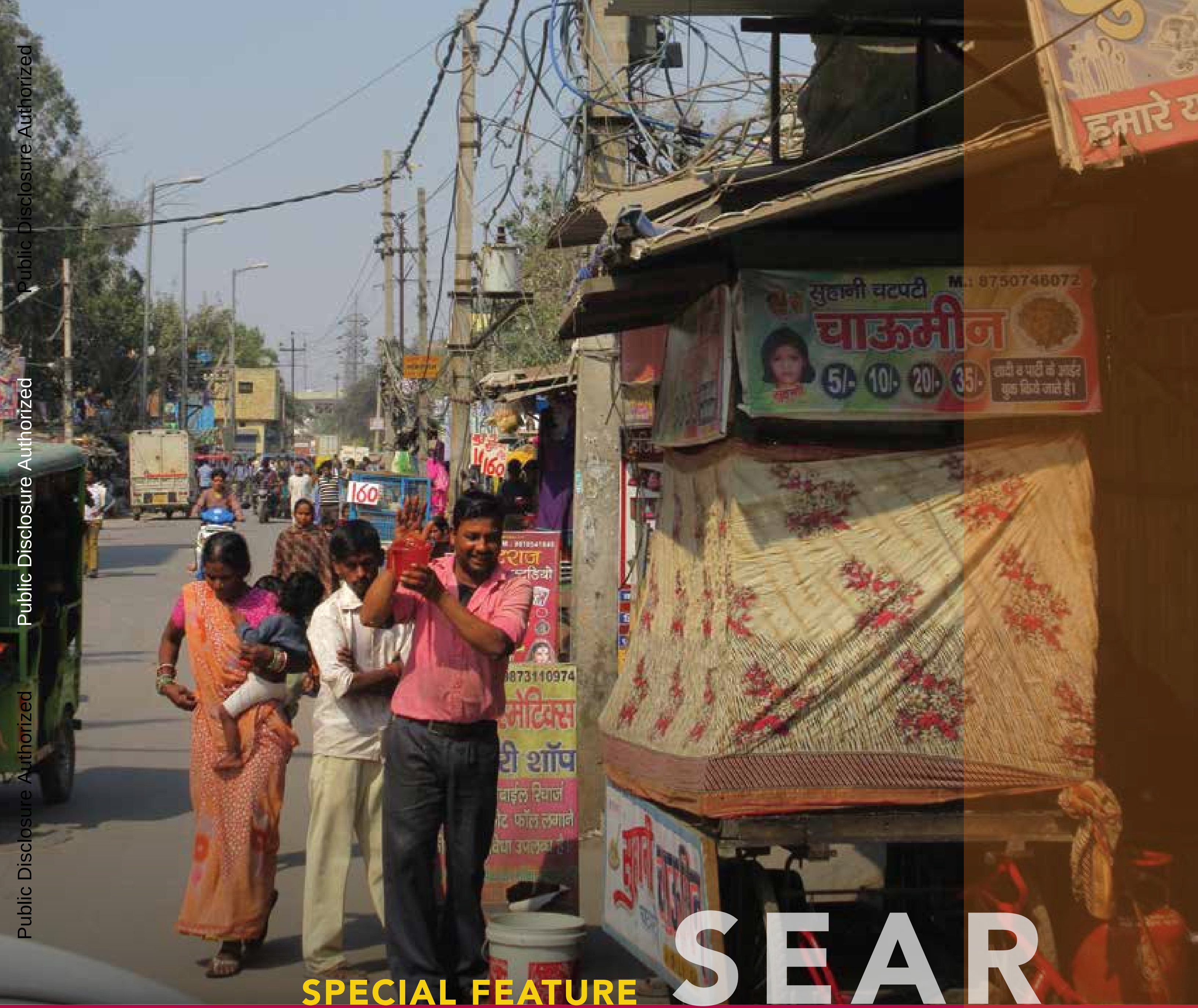

SPECIAL FEATURE SEAR

ENERGY ACCESS AND ELECTRICITY PLANNING

Mark Howells, Royal Institute of Technology;
Hans Holger Rogner, International Institute for Applied Systems Analysis; Dimitris Mentis, Royal Institute of Technology; and Oliver Broad, University College London

SEAR

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INTRODUCTION

As developing countries look for ways to achieve sustainable energy services, which is essential to lift people out of poverty, the big challenge centers around providing access for all while avoiding past pitfalls without creating new ones. The reality is that this can only occur if there is a fundamental transformation of energy systems along the entire set of resource to energy service chains—and that will necessitate greater energy efficiency and a bigger role for renewables in the global energy mix energy. Moreover it must occur at a time when projected global electricity demand calls for installing some 6.7 Terawatt (TW) of new electricity generating capacity worth an aggregate investment of $20 trillion from 2015 to 2040 (IEA, 2015).

Clearly, this is a tall order, especially given that modern energy systems are highly complex and capital intensive, constantly interacting with many other sectors like the environment, natural resource systems, and infrastructure. This means that countries will have to undertake comprehensive and systematic analyses and planning to identify and avoid (or at least minimize) expensive stop-gap measures and long-term "lock-in" into inadequate and unsustainable infrastructures. In many instances, short-term pressure for immediate action will take precedence over long-term consideration for sustainability.

In practice, comprehensive energy planning at the national, regional, or local levels is further complicated because there is no one size fits all energy system and priorities vary sharply. In developing countries, access to affordable energy services is primarily a priority for rural areas to combat energy poverty, but increasingly also in the large metropolitan areas as urbanization accelerates. These countries have 2 billion people without electricity and nearly 3 billion people relying on dirty fuels (such as firewood and animal dung) for cooking and heating. At the regional level, nearly 90 percent of people suffering from energy poverty reside in South Asia and Sub-Saharan Africa (Bazilian, 2015). And recent projections for Sub-Saharan Africa indicate an increase in energy demand of 80 percent and a fourfold expansion of electricity generating capacity by 2040 to improve the socio-economic welfare of a population twice as large as today's (IEA, 2014).

In contrast, the developed countries of Europe, North America, and Asia struggle with the replacement of aging plant and equipment—for electricity, some 40 percent of the existing capacity stock is scheduled for retirement by 2040 (IEA, 2015)—and the timely integration of new and renewable energy sources into existing infrastructures. But investment decisions are clouded by demand uncertainty due to ongoing efficiency improvements in end-use sectors, the emergence of smart grids, and potential developments of new electricity markets (such as electric vehicles). Competitive and private sector dominated energy markets rely on clear and consistent government energy-environment policies to align their investment decisions with sustainable development objectives. After all, energy system transformation is largely a capital-intensive affair that can conflict with short-term profit maximization.

The beneficial role of access to energy for socio-economic development has been acknowledged since the onset of industrialization more than two centuries ago. But there are no roses without thorns—the thorns of energy access are numerous: (i) scarred landscapes caused by mining activities; (ii) land-use change from fuel wood production; (iii) pollution emissions from fossil fuel combustion that are chiefly responsible for adverse impacts on human health, environmental degradation, and climate instability; and (iv) energy security concerns and international conflicts about the very issue of access to energy. In essence, sustainable energy avoids or minimizes these adverse side effects of energy access. Past energy transitions from wood to coal to oil were often meant to mitigate some of these consequences, only to cause new and potentially worse impacts aggravated by a seemingly ever-increasing demand for energy fueling economic growth—the blue print for unsustainability.

This paper tries to shed light on how developing countries can carry out energy planning by reviewing the available methodologies and tools, including their potential to integrate rural energy access and encourage the uptake of renewable energy technologies. It also probes how investment needs and cost-effectiveness are reflected in different analytic and planning tools—with a case study on Ethiopia. And it examines the interaction of energy planning and scenario development and how these are applied to informed policy making. The findings suggest that energy planning is essential and feasible. However, support is required to improve data collection and access, develop open accessible modelling tools, and build sustainable national capacity to undertake planning.

PLANNING FOR ELECTRICITY ACCESS

What exactly do we mean by electricity planning? It is the act of assessing the ability of a regional system to provide dependable energy services under constantly changing conditions—which involves variables such as the cost of materials and fuels, investment costs in technologies, demand levels, and distribution. Drawing on the field of operations research, planning applies advanced analytical methods and tools to make better decisions when faced with complex decisions. This activity is inherently iterative due to the fast, and potentially drastic, transformations that can take place over very limited periods of time (IAEA 1984). Developed as a way of mitigating the impacts of external events on the ability of a system to provide its specific service, this process typically identifies the most cost effective way of delivering energy to the final consumer over time (Wilson, R. & Biewald, B., 2013).

Of course, this process takes on different meanings in different parts of the world—especially in developing countries' poor rural areas and burgeoning megacities, where electricity access is a challenge in itself. Fortunately, quantitative energy modeling (using mathematically coded images of current and future energy needs), which is increasingly being used by industrial countries offers a promising tool (see box). The main barriers for developing countries are the lack of adequate data and a shortage of skilled human resources to perform the analysis. Thus, investment decisions are often based on ill-informed policy targets and the need for ad-hoc stop-gap measures. This means that targets or measures tend to focus on cheap and quick to build (often popular) technologies or emergency fuel purchases, resulting in high operating and environmental costs and expensive end-use services. Given that such actions serve the supply shortfalls of already connected consumers, increasing access is rarely part of the strategy.

Moreover, energy planning is not an end in itself and involves more than mastering energy modeling tools. Planning without subsequent implementation is an ineffective use of resources. Plus, implementation needs a functional institutional framework to ensure the availability of funding, the timely readiness of the many pieces needed for energy infrastructure investments, and a mechanism to oversee progress and control quality. In this context one should note that:

Sound project economics mobilizes the necessary finance. This is particularly the case for large infrastructure investments (Goodman and Hastak, 2006). Costs and cash-flow streams must be established and mapped to national budgetary, extra-budgetary, and external funding. The matching provides insights for estimates of investment requirements and operating and maintenance costs over the project's life-cycle. It specifies projected costs to consumers, expected revenues, and subsidies. It quantifies potential implementation barriers resulting from budgetary or financial constraints. And, depending on conditionalities, it can help leverage funding from foreign and international sources (Onyeji et al., 2012). Examples of such funding include foreign direct investment (FDI), the Clean Development Mechanism (CDM), and financing from international development banks.

Physical deployment of infrastructure needs to match schedule logistics. The introduction of a large hydropower plant serving initially a small market may exceed current electricity demand. Thus it would have to generate the needed stream of revenue to cover generating costs for many years, making it difficult to pay dividends and service debt. Then, again, shortages result when electricity demand grows faster than supply, prompting stop-gap measures and delaying economic development. Moreover, connecting millions of new customers presents a formidable logistic challenge that requires coordinating the timely and consistently staged deployment of generation, transmission, and distribution, along with developing complementary chains for system maintenance and consumer services. Failing to map these dynamically evolving factors may lead to severe demand and supply mismatches, thereby impeding the energy system's effective expansion.

BOX 1

Challenges for Energy Access in a Warmer World

Quantified models of complex systems help decision makers in numerous ways. From a technical perspective, they enable analysts to compare different system configurations without incurring the upfront cost of actually building them, which helps to mitigate uncertainty. From a practical perspective, they facilitate the design of systems in a way that accounts for local resources, demands, and constraints that are placed upon real life electricity systems. This ensures that generation meets demand in the most cost effective way and that public utilities and governmental institutions can structure tariffs to minimize consumer electricity bills. It also ensures that scenarios of future energy system developments are internally consistent. Such scenarios can serve as effective communication tools for non-partisan political commitment—which will help both to garner and mobilize private sector support and to solicit agreement and feedback from society at large. And for developing countries, even minor system improvements often have disproportionally high positive economic and environmental returns.

Functional institutions are required to support the implementation and operation of an expanding energy system. These include market regulators, system operators, vendors, environmental protection agencies, line ministries, educational institutions, and public-private sector partnerships (Bazilian et al., 2011). Jointly these institutions are tasked with developing milestones for implementation (IAEA, 2009) and inter-ministerial coordination

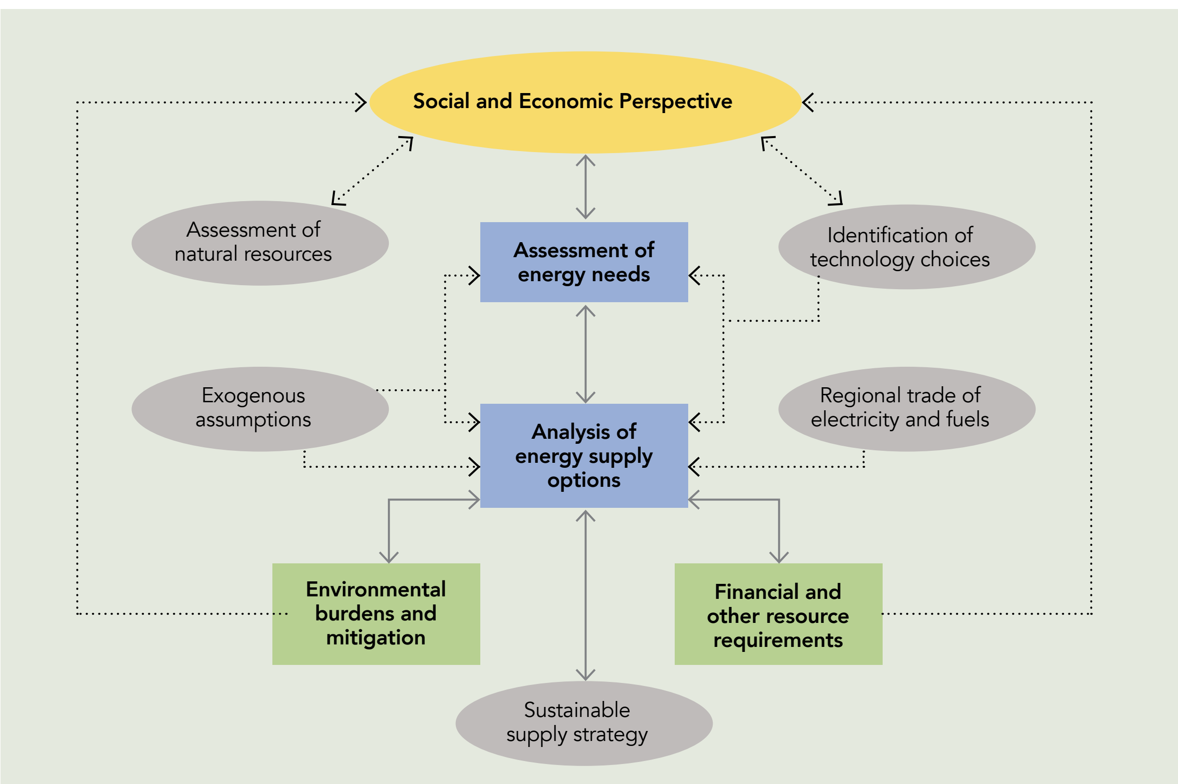
TOOLS AND METHODOLOGIES

The key to such an enormous undertaking as energy planning is the availability of energy planning toolkits, which, at least in their contemporary form, date back to the oil crises of the 1970s, when governments and industries were caught by surprise by an unforeseen and unprecedented curtailment of global oil supplies. Initially these models focused on sector specific issues such as ensuring a sufficient supply of oil or expanding electricity generating capacity. But they were later expanded to also account for energy-economy-environment interlinkages or externalities (see figure 1)—leading to a vastly improved and increasingly inclusive energy systems planning process (Bhattacharyya, C., and Timilsina, G.R., 2010).

Models and toolkits were primarily developed by, and for use in, the industrialized countries of the OECD and the former CMEA (or Comecon), which had relatively good energy statistics and well educated energy analysts. As a result, these tools are, for the most part, ill adapted to applications in developing countries. Adapting models to the data situation in developing countries is not only aggravated by the tools' data intensities but also by a lack of options for simplified yet meaningful reduced-form model setups. Proprietary codes, "closed-source" features, and often poor documentation make their simplification difficult (Howells et al., 2011). Recent simplified open source models—such as OSeMOSYS (Howells et al, 2011), Temoa (Hunter et al, 2013), and SWITCH (i4e, n.d.) have a stripped down code base allowing analysts to add analytical features. This reduces barriers to entry for new analysts and developing country practitioners (DeCarolis et al., 2012 and Howells et al., 2011), although it limits their off-the-shelf analytical functionality.

Given the evolving nature of energy systems, a continuous advancement of the modeling tools is inevitable. Delineating energy access or poverty in mathematical terms (Nussbaumer et al., 2013), costing energy access (Fuso Nerini et al., 2014), and developing open access energy planning tools (Bazilian et al., 2012) are new and expanding fields. The challenge is to align new model features such as energy access with the moving "goal posts" of energy systems that become more dynamic (Bazilian et al., 2013) and integrated well beyond the traditional energy system boundaries (Howells, M., and Rogner, H.-H., 2014).

FIGURE 1 A framework for comprehensive energy planning



Source: Rogner, 2011

Energy systems models

Electricity systems models are tools used by electricity analysts (such as engineers, economists, and planners) to manage and plan the electricity system, trade electricity, and expand generation capacity (Foley et al. 2010). Here, we focus on three types.

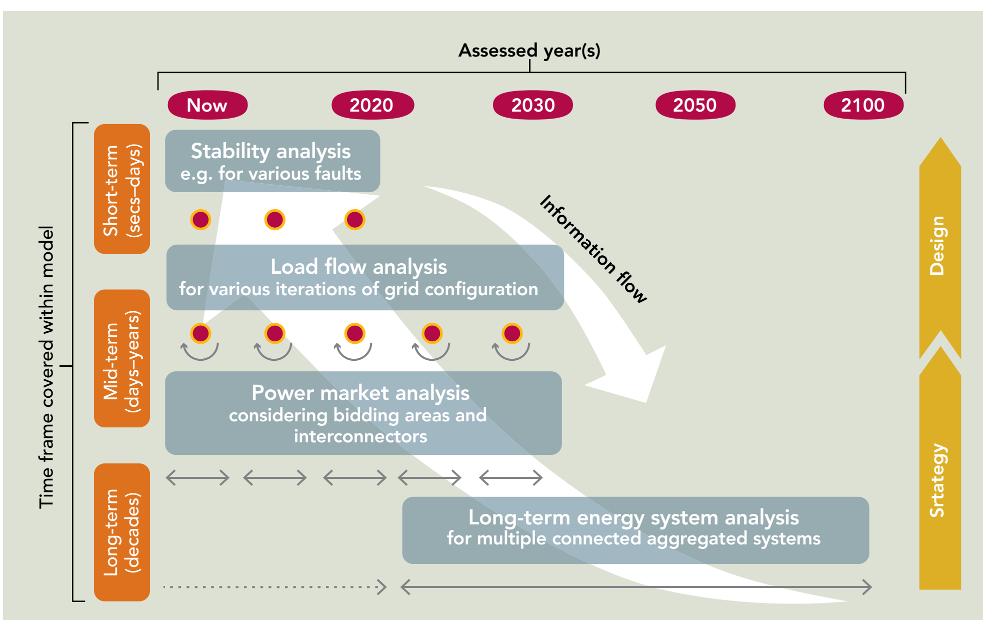
- *Macroeconomic or "top-down" models.* These include econometric, input-output, and computable general equilibrium approaches (Welsch 2013). They are driven by projected developments of major economic indicators, using prices to balance demand and supply within the energy sector as well as the rest of the economy. They provide insights on broad relationships between economic development and the associated energy demand and supply. And they may or may not (but usually do not) include details on technology.
- *"Bottom-up models.* These are largely technology driven—accounting for the physical configuration of the energy system's technologies and infrastructures, their vintage situation, energy efficiency, and economic and environmental performance. They are driven by the usually hard-wired requirement that supply has to meet demand, which is externally determined (possibly by a macroeconomic model). The most popular ones are optimization models, which identify optimal pathways for meeting demand; optimal can be least cost, highest level of energy security, or fastest access to energy services.
- *Hybrid models.* These incorporate aspects of both bottom-up and top-down models, and are either integrated or "soft-linked" (data is explicitly transferred between two stand-alone tools in an iterative manner). Linking and integrating models from different scientific disciplines has become a necessity for understanding energy-related greenhouse gas (GHG) emissions and land-use changes, along with their impacts on climate change (and vice versa). Integrated Assessment Models (IAMs)[1] account for elements that cross boundaries of different domains (especially between energy, atmosphere, oceans, and land-use).

Focusing on bottom-up models, which are most relevant for identifying investment requirements in developing countries, they are chiefly characterized by their temporal scope (figure 2)—which can range from maintaining voltages (stability analysis) to the operation and dispatch of electricity (load flow and market power analyses) to investment requirements (long-term energy system analysis). Models focusing on AC or DC load flow analysis may serve to investigate various grid configurations. Such models may cover timeframes of hours or years. Based on the derived transmission capacities, steady-state, transient, or dynamic stability analyses may serve to assess disturbances in power systems. Stability analyses usually cover timeframes of up to several minutes. They may provide important insights on the design of the components of the transmission and distribution system.

Geographic information system models

Cost-effective electricity supply systems serving rural households and businesses are diverse and site specific, meaning that the cost-optimal technology choice depends on several parameters. These can be geophysical, technical, economic, or social—such as local population density, distance to the grid, fuel costs, and electricity usage, respectively—and many are strongly spatial in nature (like wind regimes, potential micro-hydropower sites, settlement positions, and grid expansion). Developing a clear transparent approach to capturing these parameters and translating them into potential technol-

FIGURE 2 The temporal scope of power sector models



Source: Welsch, 2013

ogy suites to meet energy access goals, is crucial to informing effective policy.

Geographical Information System (GIS) models respond to this need by enabling the analyst to assess the cost of electricity provision at each specific location in a given area. By combining detailed geo-referenced layers of data for each relevant parameter, site specific investment needs and energy cost implications of competing technological systems can be compared in space and time.

The use of GIS-based analyses has increased since the mid-1990s with a clear focus on using levelized energy cost[2] (that is, the breakeven cost) for choosing the appropriate technology. The value of the geo-referenced approach in these situations lies in its ability to combine comprehensive information relating to site specific technological information to in depth regional resource availability data thus assessing an "integration of all the possibilities" for electrification (Amador and Domínguez, 2005).

Further, the application of such tools to remote areas, where information is scarce, enables and supports analyses that could otherwise not take place. The use of remote sensing data and technologies, combined with the interpolation capabilities of GIS models can, when applied to macro-economic and statistical data for a given area, "answer some of the key questions" relating to energy planning and rural electrification (Szabó et al., 2011). Take the following examples:

In some Sub-Saharan African countries, the Network Planner model is used to compare the implications of either extending the national grid, rolling out solar PV household systems supplemented by diesel generators for productive uses, or opting for low voltage diesel-based mini-grid systems (Kemausuor et al., 2014). In the case where grid extension is the cost optimal solution for a given location, the tool assigns each settlement an economic radius that the grid would reach from such a starting point. Using a modified version of Kruskal's minimum spanning tree algorithm, it then connects the locations using the least additional kilometers of additional grid (Parshall et al., 2009).

In Nigeria and Ethiopia, the ONSSET electrification tool is used to develop a cost model for comparing the levelized cost of electricity generation of grid extension with mini-grid and off-grid diesel-based and renewable options (Fuso Nerini et al., 2015). It generates a set of boundary conditions that inform a GIS related algorithm assessing grid compatibility of all non-connected settlements and, in case of negative outcomes, selecting the most cost effective mini-grid or household level solution (Mentis et al., 2015)

In northern Brazil, GIS analysis is used to answer questions of renewable energy management in semi-arid rural areas (Tiba et al., 2010). By crossing a variety of data banks relating to (i) raw data for infrastructure, resource, and socio-economic parameters and (ii) technological data for solar power, water pumping requirements and other renewable energy systems, the study generates a representation of "the best localities for inclusion of a determined renewable energy technology."

DEMAND FORECASTING FOR POOR COUNTRIES

Of course, a critical element in these models is how much energy will be demanded. Typically, electrification efforts that focus on connecting new households are driven by policy, while for commercial users, the driver is economics (Gaunt, 2003).

Starting at the household level, where there are relatively high connection and distribution costs, demand projections for electrification efforts are typically engineered as a function of a limited number of key parameters (such as population density, location, and governmental targets for energy access). For example, the Network Planner Tool uses parameters like energy intensity per rural and urban household, projected population growth, and economic demand elasticity to derive geo-spatial demands. Similar end use accounting (Bhattacharyya and Timilsina, 2009) techniques to derive rural and urban household demand are employed by the popular LEAP (Heaps, 2014) and MAED (IAEA, 2006) models (which do not provide any geo-spatial information).

At the country level, a variety of methods are used to project demand for total electricity sales (which often include little or no explicit geo-spatial consideration). (Bhattacharyya and Timilsina, 2009) group these approaches into end use accounting and econometric. An end use accounting approach may begin with exogenous and detailed economic projections that are delineated by economic subsector, with energy use split between thermal and other requirement, and assumptions made about how that energy intensity will change over time. These are then combined with potential fuel substitution for thermal requirements to make projections by sector and fuel. Similar, but more flexible approaches are available in LEAP. Less complex approaches include simple econometric regressions with population and economic growth. Other approaches account for feedback between the cost and configuration of the energy sector with the demand for its fuels. For example, fuel price elasticities by sector may be accounted for directly (Loulou and Lavigne, 1996) or via broader macroeconomic feedback (Howells et al., 2010; Winkler et al., 2007).

In addition, metrics have been developed to support governmental goals for energy access and inform demand projections. The World Bank's Multi-Tier approach (World Bank, 2015) determines tiers of energy intensity per household, with each tier associated with different levels of electricity use—ranging from (at the lowest level) lighting and cooking to (at the highest level) services that provide comfort (such as air-conditioning). Other metrics account for a broader range of parameters involving other aspects of energy poverty and development, such as the Multi-dimensional Energy Poverty Index (MEPI) (Nussbaumer et al., 2013) and IEA Energy Development Index EDI (IEA, n.d.).

CASE STUDY: ETHIOPIA

To better understand how these tools work in practice, we explore what would need to happen in Ethiopia to provide better electricity access and services in a cost-effective manner. We use two tools: (i) the ONSSET –GIS-based tool for rural electrification to determine the cost optimal way of providing high levels of electricity access; and (ii) the OSeMOSYS tool to determine the cost optimal way of expanding grid-based bulk generation. The combination of these two tools forms a consistent approach to minimizing the cost of electrification (Bekker et al., 2008) while concurrently meeting the economics of supplying bulk quantities of low cost, reliable electricity. Current per capita electricity consumption in Ethiopia is as low as about 50kWh—compared to 13,200kWh in the United States and 1,750kWh in neighboring Egypt (World Bank, 2014).

Providing high levels of electricity access

We begin by considering the least cost configuration of grid, micro-grid, and stand-alone technologies to meet two rural (50 and 150 kWh/capita/year) and one urban electrification target (300 kWh/capita/year). As figure 3 shows, a higher target results in the deployment of grid and mini-grid systems, with remote and low density populations relying on stand-alone electrification. The change in technology from high to low is indicated in table 1, with a noticeably large shift to stand alone systems.

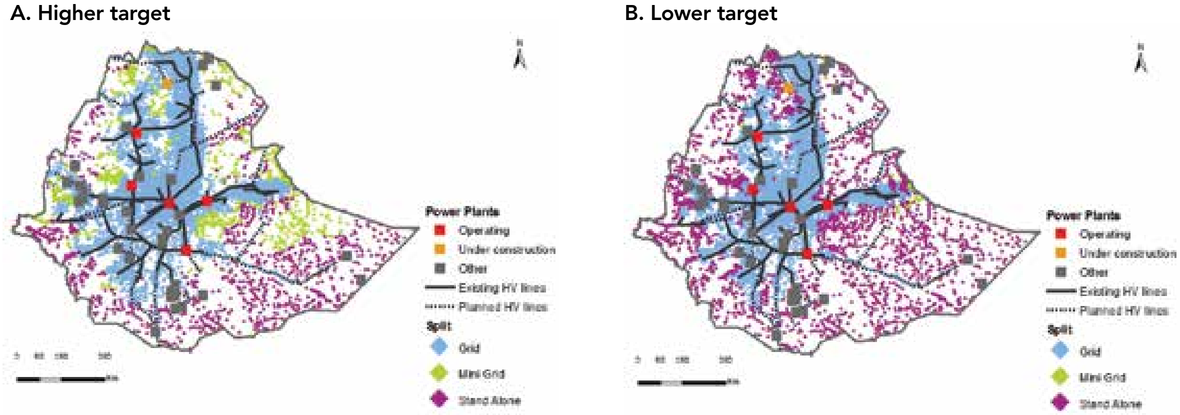
Underlying the shift in technology is how the cost of electricity. Figure 4 indicates how the levelized cost of supply on a geo-spatial basis changes in response to the higher and lower supply targets. With higher levels of provision, the cost per unit is reduced in rural areas. With lower targets, unit costs are higher. Note that costs near the grid in urban areas remain unchanged, following their constant electrification target.

What would happen if electricity costs increase where there is no systematic deployment of solar and mini-grids? As figure 5 (panel A) shows, if the grid is not extended and users only have access to diesel generators, electricity costs are high. But if the PV market becomes more fluid, or the government helps facilitate investment, the cost of rural electrification drops significantly (Figure 5, panel B). This occurs because the deployment of PV stand-alone solutions decreases the levelized cost of electricity in some settlements as compared to just diesel stand-alone options. PV stand-alone technology would be more viable than diesel stand alone for 22,624,921 people (or 32 percent of the population that needs to be electrified). If grid extension and mini-grid technologies were to contribute to the electrification mix of the country, only 656,767 people would be electrified by stand-alone systems (diesel, PV).)

Thus, an optimal deployment strategy would include extra grid extension and the deployment of micro-grids—information that could be used to support better policy-making. And knowing the cost optimal deployment characteristics could be used to develop specific policies—ranging from state-led deployment to facilitation of market development. At this point, Ethiopia is undergoing rapid expansion in its generation capacity. Consistent with the most recent eastern African power pool development plan (EAPP/EAC, 2011), the power system grew by 20 per-

FIGURE 3 Optimal electrification mix in Ethiopia

A. Higher target **B. Lower target**



Source: Author's calculation based on Mentis et al 2016 b.

TABLE 1 Optimal split for new connections

(Population-based for different rural electrification targets)

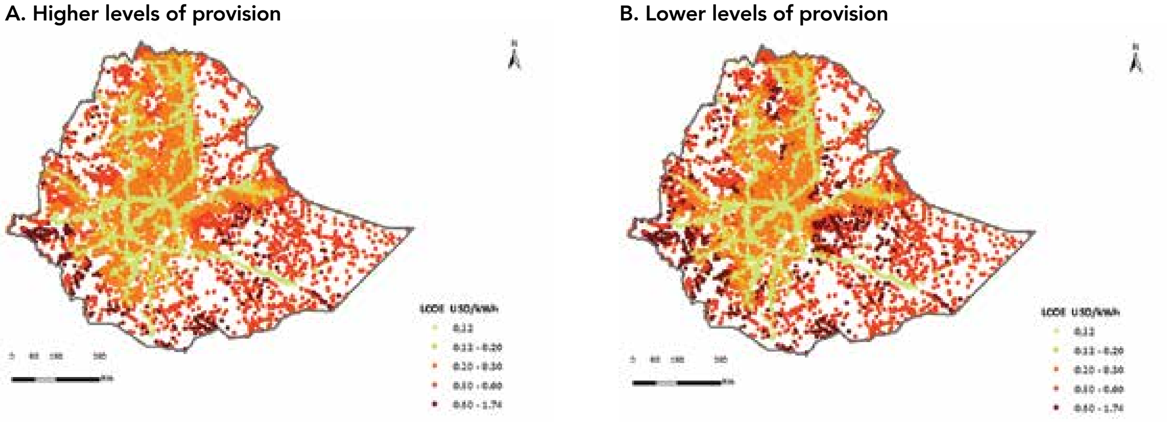
SPLIT	POPULATION (150/300)	POPULATION (50/300)	CHANGE
Grid	65,431,650	62,270,395	↘–4.8%
Mini Grid	3,958,695	245,825	↘–93.8%
Stand Alone	656,767	7,530,892	↗1046.7%

Source: Authors' calculations

FIGURE 4 Higher levels of provision mean lower per unit rural area costs

Spatial levelized cost of electricity

A. Higher levels of provision **B. Lower levels of provision**

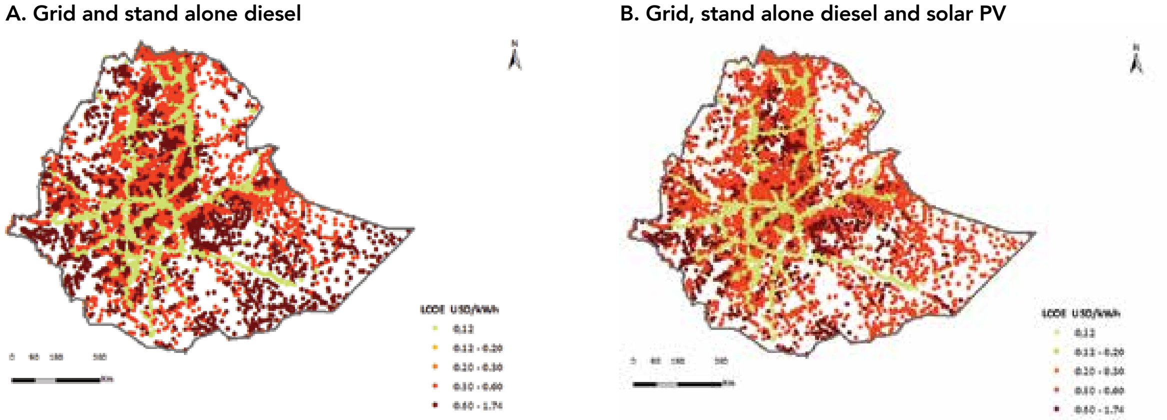


Source: Author's calculation based on Mentis et al 2016 b.

FIGURE 5 A case for more grids and PV solar

(Spatial levelized cost of electricity for the electricity access targets 150–300 kWh/capita/year

A. Grid and stand alone diesel **B. Grid, stand alone diesel and solar PV**



Source: Author's calculation based on Mentis et al 2016 b.

Note: Left panel: Population already connected to the grid is grid connected and the rest are electrified by stand-alone diesel.
Right panel: Population already connected to the grid is grid connected and the rest are electrified by stand-alone diesel and PV solar.

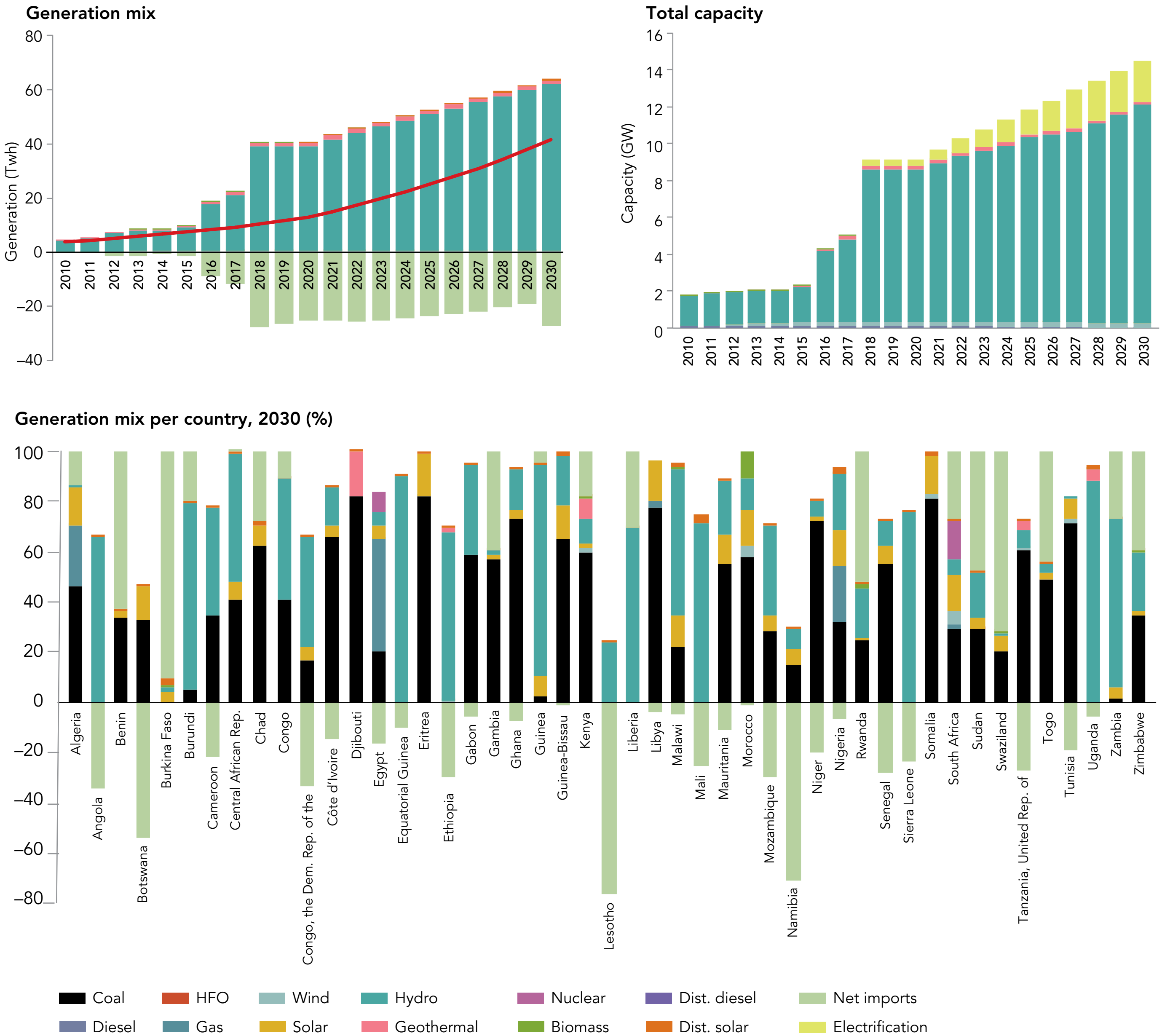
cent between 2013 and 2016, increasing by over 4.7GW. One baseline projection (WB) of electricity growth is around 5 percent per year.

Pinpointing the lowest cost route for grid expansion

To determine the lowest cost expansion of the grid-based electricity system, we use the Open Source energy Modeling System (OSeMOSYS)—which is driven by demand for "grid" electricity resulting from the ONSSET analysis, as well as a national projection of other (bulk) demand growth (based on GDP projections). It captures potential candidate power plants, fuel costs, and resource availability (fossil and renewable) to calibrate the model cost and performance data relating to existing power plants and their retirement schedule. A cost optimal system is then calculated (Howells et al 2011). On the resource front, hydropower is expected to form the foundation for Ethiopia's electricity system (Taliotis et al 2016), although recent analysis (IRENA, 2014) also indicates relatively high potentials of non-hydropower renewables available. Plus there are limited reserves of crude oil and larger quantities of natural gas. The model assumes that newly electrified households meet their demand target of 150kWh per capita in rural areas and 300kWh per capita in urban areas.

Our results show that generation investment is dominated by hydropower (Figure 6 panel A), with large quantities used for export—although there are significant new investments in capacity required for electrification (indicated hashed lines in figure 6 panel B). But if trade in Africa is to reach its cost optimal potential, Ethiopia will need to join a number of countries that generate significant quantities of electricity for export by 2030 (figure 6 panel C) (Taliotis et al., 2016).

FIGURE 6 Hydropower will dominate in Ethiopia



Source: Taliotis et al., 2016 and author's calculation based on Mentis et al 2016 b.

INVESTMENT NEEDS AND SOURCES OF FUNDING

Between 2010 and 2030, an investment of $12 billion to 279 billion per year will be needed to provide energy access for all (Bazilian et. al. 2014). These values vary significantly as a function of electricity demand per capita. Locally, the scale of investment depends on a variety of parameters, such as geography, resource endowment, and investment risk. Recent studies estimate that the cost of electrification can range from less than $100 per household for basic access solutions, to about $7,000 per household for high targets of access (Fuso Nerini et al., 2014) .

Once investment needs are clearly delineated, a variety of options are available to raise and channel funds—at the international, bilateral, and national levels, involving the public and private sectors and nongovernmental organizations (NGOs).

National and local governments play a key role in creating an enabling environment for private energy investments based on clear legislation, plans, policy, and effective institutions. The extent to which these will be called into play can be derived from planning, indicating the market size, scale of investment, and operation. More direct intervention is, in no small part, dependent on the type of technology and investment that needs to be made.

For example, if solar panels are to play a key role, they might be sourced from a producer country—which might supply soft loans or other subsidies to secure the sale and promote development.

At the *international level,* financing might be forthcoming if expanding the system results in better environmental performance compared to "business as usual." Perhaps the expanded system reduces carbon dioxide, by replacing fossil fuels. If so, it may be eligible for financing support through global facilities such as the Global Environmental Forum (GEF) or the Nationally Appropriate Mitigation Action (NAMA) facility. Or perhaps it will reduce household woodfuel consumption in homes and thus demonstrably reduce deforestation. If so, REDD (Reducing Emissions from Deforestation and forest Degradation) funding might be available. Should transparent development progress be demonstrated (which the planning will help establish), a variety of tied or untied aid and trade potential might be unlocked through bilateral, regional, or global agreements.

The *public* sector can directly support electrification and power system expansion via several routes. Common ones include: (i) fund raising through increased tariffs, cross subsidies, or taxes; (ii) providing tax credits; (iii) providing secure power or fuel purchase agreements; (iv) providing grants or direct payments; (v) disseminating information and building capacity; and (vi) supporting the development of supply chains. Again the type of measure will be a function of the technology choice. For example, a hydropower plant may be supported by a power purchase agreement. But a coal fired power plant may need facilitation with respect to granting mining rights, a fuel supply agreement, and a power purchase agreement. The power purchase agreements may also vary. If climate change is expected to affect water flows, hydropower sales may need to tailor the agreements to mitigate associated risks (which can be uncovered in extended energy modeling exercises) (WB, 2015).

The right enabling environment can be used to secure funding through local NGOs, with less "hands on" policy intervention—or even no intervention at all, except for information dissemination. For instance, cooperatives have been used to set up community owned and operated local energy systems. Additionally, local NGOs can support local electrification projects and help create enabling environments for energy access at the community level.

POWER PLANNING AND POLICY COHERENCE

Given that energy needs to be both socially acceptable and environmentally compliant, it is vital that energy policy is integrated into broader development strategies. Consider, for example, expanding education to the rural poor in a least developed country. This will require not only building schools but also supplying electricity. But expanding the energy sector can be capital intensive; the demands for its fuels may be inelastic and taxable; and there might be a need for significant imports or produce exports. As a result, fiscal and economic policy would need to be consistent with the needs of the energy sector. If expenditure on investments is too high, for instance, it may crowd out funding needed for other purposes. In the longer run, high upfront investments may result in low running, and therefore low electricity prices. Low prices may reduce the cost of production factors and boost economic growth. The energy sector is often the most important contributor to GHG emissions. Yet environment ministries may be called on to communicate GHG projections and mitigation targets.

The need for integration becomes particularly clear where there are physical links among the critical resource systems. The term nexus[3] is increasingly being used to describe the interlinked nature of resource systems. The importance of interlinkages in the supply chains that provide water, energy, and food has been raised by the IAEA (2009), among others, emphasising prudent integrated management of climate, land-, energy- and water-use (CLEW) strategies. As gains may be had with increased integration in these supply chains, it is argued that there is a clear need to develop quantitative frameworks to support future sustainability policies (Howells and Rogner (2014).

Links to climate, water, land, and other resource planning

Planning approaches have been developed to study and develop policy for resource management. However, these approaches can be lacking—especially when different resource systems are tightly interwoven (UN, 2014). Existing approaches typically examine future development scenarios of one sector, with little account of consistent and concurrent scenarios of other sectors. Often termed "integrated,"[4] such planning processes make inter-sector linkages explicit, but they do not necessarily look beyond those. Resource planning approaches typically assume that the related sectors are static, or that their development is not fundamentally changed by the primary sector being considered. This can result in important feedbacks being ignored or overlooked (M. Howells et al., 2013a). For example, a drying climate change may drive up energy prices at a time when energy needs become amplified. Unless considered concurrently under the same scenario drivers, such a negative and reinforcing situation may go undetected. Efforts to overcome these methodological shortfalls are beginning to be made at a policy level, notably EU strategic environmental assessments (EU, n.d.).

While in their infancy, nexus studies have started to zoom in on exploring different geographical scales: from global (United Nations, 2014) to regional (Smajgl and Ward, 2013; UNECE, 2014)) and national (Hermann et al., 2012; M. Howells et al., 2013b; Macknick et al., 2012; Sattler et al., 2012). At the sub-national level, Bartos and Chester (2014) illustrate missed opportunities in the United States from the lack of formal integration of the water and energy service infrastructure in Arizona. In Sub-Saharan Africa, a major World Bank study (WB, 2015) that covers over 40 countries combines agricultural, hydrological, climate, and energy modelling to assess the interference and climate vulnerability of each. This allowed for not only a resource consistent approach but also a regionally consistent analysis. And it was delivered by a small team using open tools[5] over a relatively short period—which bodes well for making such approaches easily available.

Role in economic, social, and regional development strategies

Energy provision to the poor is vital. Consider the typical least developed country, which is highly dependent on agriculture. Electricity is needed to support enabling basic activities such as lighting and powering ICT devices, and mechanical power and heat are needed to farm and treat crops. In addition, there is a strong correlation between electricity use per capita and human development, with countries with higher per capita use ranking higher on the human development index. Studies in rural states of India have pointed out the potentials for increased literacy relating to electricity access (Kanagawa and Nakata, 2008). Others have theorized that such relations are best described as saturation phenomena where we observe a steep rise in human development relative to energy demand for energy-poor nations, a moderate rise for transitioning nations, and essentially no rise in human development for energy-advantaged nations (Martínez and Ebenhack, 2008).

At the regional level, extending modeling to look across borders has become important to assess integration, trade, and security issues. At the global level, extending models to analyze the potential development of power pools is also occurring. A power pool coordination program may use a computer generated power pool "master plan" to help understand how best to mobilize resources (SAPP, 2009) or the role of technology deployment where resource rich countries may supply others (IRENA, Forthcoming). Other examples include continental efforts, such as the Program for Infrastructure Development for Africa (SOFRECO, 2011).

CAPACITY BUILDING FOR PEOPLE AND INSTITUTIONS FOR PLANNING

Without in-depth national energy planning capacity, the poorest will always be at the mercy of big industry and relying on the goodwill of the international and donor community (Rogner, 2011)—especially given that no one size fits all with respect to the energy system. Local conditions are unique, physically, politically, economically, and socially. Thus local capacity to develop, run, analyze, and interpret model results is crucial. Without the capacity to undertake this cornerstone of energy policy development, national development strategies may be ill informed with unwanted consequences.

This is particularly the case with changes to capital intensive energy investments or radical policy reforms, which will likely require more capacity development to obtain the needed skills to manage the new market situation. Take the case of reforms coupled with multinational operations within a larger regional market that also involve the entry of private players (AfDB, 2013). Such skills would include: (i) developing energy balances and projections; (ii) configuring energy supply and trade scenarios; (iii) estimating financing as well as the institutional support; and (iv) understanding broader metrics for sustainable development and cross-sector impacts ((IAEA, n.d.)), (Howells and Roehrl, 2012)).

Capacity building should be seen as a long-term exercise—in effect, an investment project with limited immediate, higher long-term pay-offs. According to the African Development Bank (AfDB, 2013), "in order to ensure sustainability, capacity building should be migrated over time to the Centres of Excellence, tertiary institutions, and the utility affiliated academies of learning." Ideally this should build and regional networks of experts, trainers and trainees.

CONCLUSION

Thus, energy planning is feasible and essential. There is a strong imperative to calculate quantitative and internally consistent scenarios of a country's energy sector development to understand the needed institutional, incentive, technological, and financial requirements. This information can also be used to: (i) help harmonize policies, (ii) plan across different resources systems, and (iii) inform energy and technology trade. Scenarios are developed with models, and given the strategic nature of the energy sector, models and the capacity to run them are required for both regions and countries.

At present there exist a useful, but limited set of accessible cases studies and open toolkits. This means that support efforts should focus on assisting data collection, contributing to open modeling development, and building human capacity to analyze the energy sector. Such capacity building should include, but go beyond, technocrats. It should also include the establishment of centers of excellence, tertiary education, and networks of experts—the latter will be needed to ensure that the planning process is sustainable and will continue after short-term assistance ends.

NOTES

1. Notable integrated assessment models include: DICE (Dynamic Integrated Climate-Economy), RICE (Regional DICE), MERGE (Model for Estimating the Regional and Global Effects of greenhouse gas reductions), MESSAGE-MACRO, IMAGE (Integrated Model to Assess the Greenhouse Effect), IMAGE/TIMER (Targets IMage Energy Regional), MiniCAM (Mini Climate Assessment Model), GCAM (Global Change Assessment Model), WITCH (a World Induced Technical Change Hybrid System), DNE21 (Dynamic New Earth 21), MIND, ReMIND (Regional Model of Investments and Development), AIM/CGE (Asian Pacific Integrated Model). (Després et al., 2015)
2. The levelized cost is the total costs (including capital investments, operating costs, and financing costs) divided by the total energy output over the lifetime of the system.
3. Nexus refers to the interplay and interconnections among different societal or natural systems or resources. Most commonly, it covers water, energy, and food, but it can also involve security, eco-systems, climate, sanitation, health, and gender (see for instance Beck and Walker, 2013; UNECE, 2014)
4. Examples include Integrated Water Resource Management (IWRM), Integrated Energy Planning (IEP), Integrated Land-use Assessment (ILUA), etc.
5. For the electricity modelling OSeMOSYS was employed.

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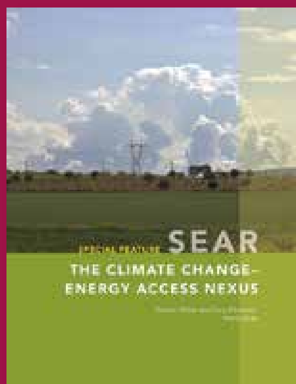

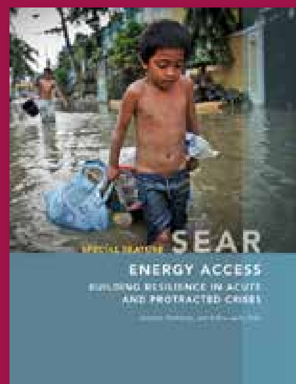

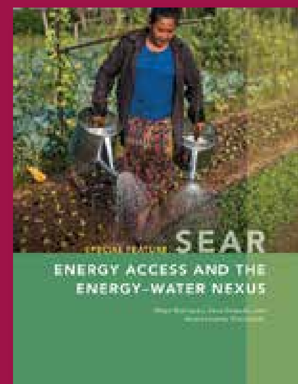

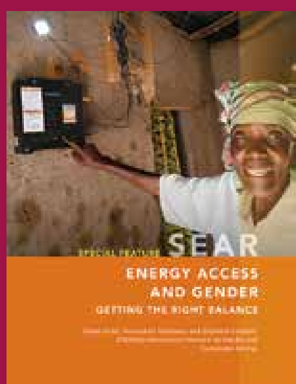

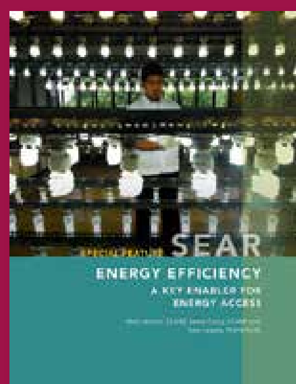

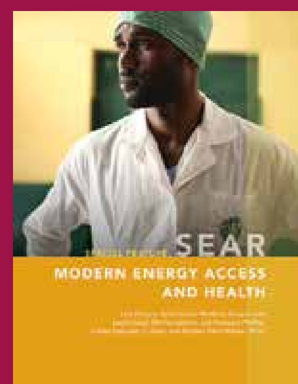

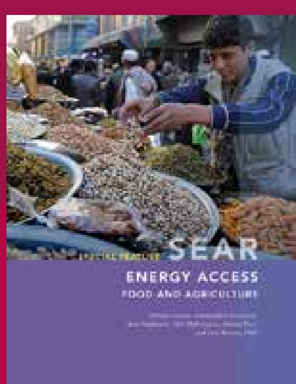

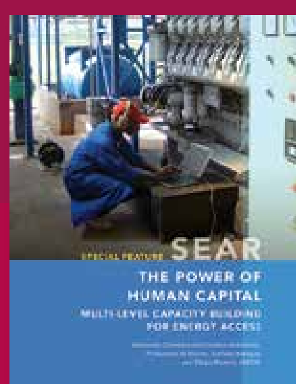

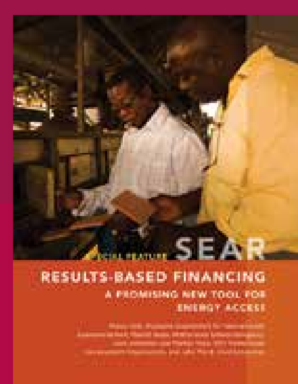

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