Synthesis Paper: EEG contributions to energy modelling

This paper provides an overview of the contributions of the Applied Research Programme on Energy and Economic Growth (EEG) to energy modelling in the context of the wider literature and its policy implications.

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Abstract

Energy plays a vital role in economic growth and prosperity. It underpins almost all the UN SDGs. The systemic energy transition necessary to achieve the SDG 7 requires nationally driven strategic energy planning processes in developing countries. Energy modelling can help planners and decision-makers navigate the complexities and interdependencies in strategic energy planning. For this reason, the EEG programme funded numerous energy modelling activities supporting strategic energy planning in developing countries. This paper assesses the wider context of energy modelling (why it is important and the range of energy modelling approaches available). It then reviews the energy modelling activity supported by EEG over the period 2017 to 2022 and how that experience led to the formation of a roundtable of development partners to review approaches to support modelling in developing countries and the development of a set of principles to guide future action. Finally the paper reviews lessons emerging from the EEG-funded modelling research and suggests additional further areas for future research. To illustrate use of the Round Table Principles in practice, an annex reviews the EEG sponsored modelling projects themselves against that code of practice.

Key words: Energy modelling; strategic energy planning; Roundtable Initiative on Strategic Energy Planning; energy system models; energy-economy models; input-output models; Computable General Equilibrium (CGE) models

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1. Introduction

The Applied Research Programme on Energy and Economic Growth (EEG) was a UK Aid-funded programme aimed at delivering ground-breaking research to address some of the most pressing energy-related challenges in Sub-Saharan Africa and South Asia. One of these critical areas was strategic energy planning and the use of modelling techniques.

In its six years of implementation, from 2016 to 2022, EEG funded several research and capacity-development initiatives utilising energy modelling approaches to support policy making in developing countries. This paper seeks to draw on that experience by reviewing the role of modelling plays generally in strategic energy planning (Section 1) and summarising the modelling research supported by EEG against that context (Section 2). It will then go on to discuss the emergence of a set of strategic energy planning principles derived from that combined experience (Section 3), before concluding by identifying other key policy lessons from EEG modelling activity and possible areas for future research (Section 5). Finally, Annex 1 provides an assessment of EEG energy modelling research against the set of key strategic energy planning principles derived in section 3.

2. Context

What is energy modelling and why is it important?

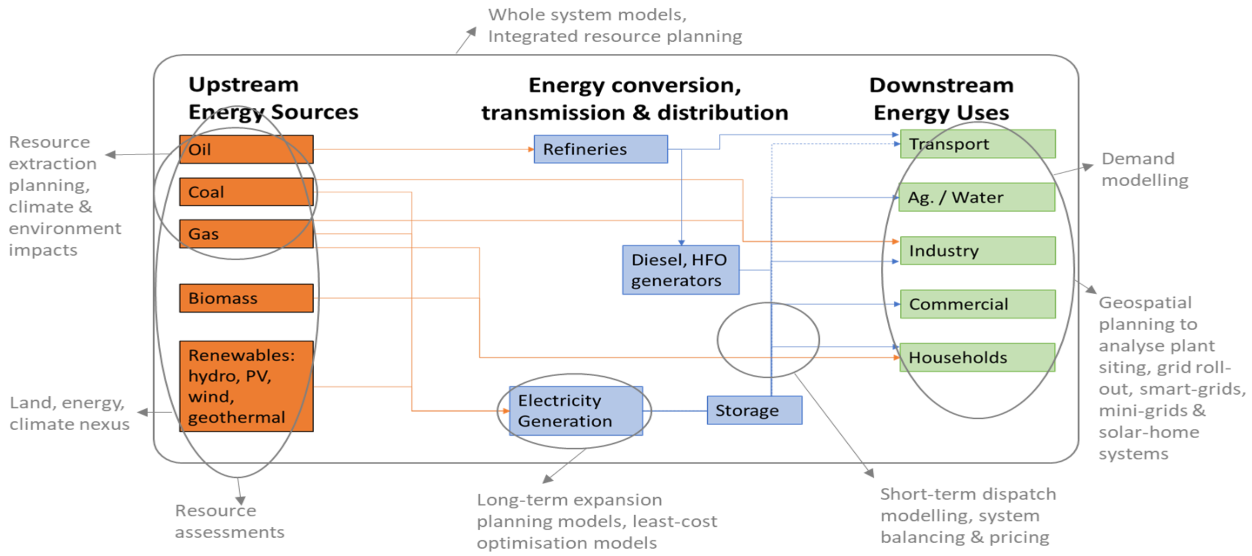
Energy plays a vital role in economic growth and prosperity. It underpins almost all the United Nations (UN) Sustainable Development Goals (SDGs), from poverty eradication to promoting advancements in health, education, water supply, industrialisation, and combating climate change. SDG number 7 aims to "'ensure access to affordable, reliable, sustainable, and modern energy for all" (United Nations, 2015) by 2030. The UN estimated that, in 2020, 733 million people did not have access to electricity, and 2.4 billion people still used inefficient and polluting cooking systems (UNDESA, n.d.).

The systemic energy transition necessary to sustain this global goal requires the careful planning of energy systems at the international, national, and sub-national levels. Strategic energy planning involves the gathering and use of evidence about the different parts of the energy system and a robust set of assumptions on future trends to identify the energy system pathways of a country or region in line with its strategic goals. Evidence-based energy planning can help policymakers better understand the key trade-offs and tensions between different energy policies and other national strategic goals such as social equity, fiscal policy, job creation, energy security and geopolitics, climate change resilience and mitigation, and environmental sustainability.

The central concept in strategic energy planning is the energy system. An energy system can be defined as "the process chain from the extraction of primary energy to the final use of energy to supply services and goods" (Machado, et al., 2020). It comprises three main areas (Figure 1). First, the upstream energy resources' extraction (e.g. oil, gas, coal, biomass) or collection (e.g. hydro, wind, solar). Second, the energy resources' conversion (e.g. through refineries, power plants and generators), transmission and distribution. And third, the downstream energy uses to meet the different energy needs in the sectors of society, e.g., in transport, water, agriculture, industry, commercial, and households.

To navigate the complexities and interdependencies in strategic energy planning, planners and decision-makers often make use of different analytical and modelling tools and approaches (Figure 1). For example, within upstream system planning, the assessment of the available energy resources needs to be undertaken in conjunction with planning for their extraction or importation to meet present and future energy demand, while considering the environmental impacts and the competing needs of water, land, food, and decarbonisation. In energy generation, transmission and distribution, long-term expansion planning models and least-cost optimisation models are often used to define the best pathways for planning the future expansion of energy systems according to prioritised strategic goals. On the downstream side, current and future sectoral energy demand must be modelled to properly balance the system and define the appropriate pathways for the roll-out of the system's expansion, an analysis often supported by geospatial data and models. Finally, whole-system models and integrated resource planning address the needs of a holistic view of the entire energy system and interdependent ones.

Figure 1. Different analytical and modelling tools for strategic energy planning



Source: Roundtable Initiative, et al., 2021

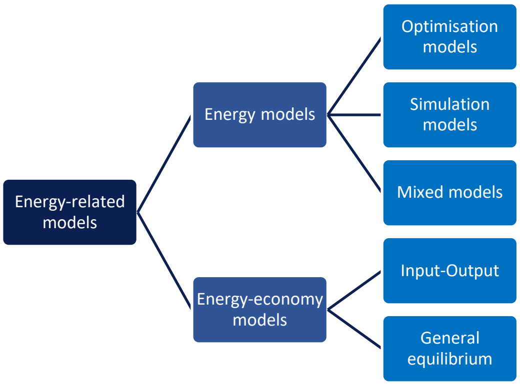
The bottom line is that the use of effective planning models and tools is fundamental for decision-makers to study different scenarios and policy choices in a comprehensive manner. A common aphorism attributed to the statistician George Box (1979) states: “All models are wrong, but some are useful”. Indeed, all models, even the most complex ones, only reflect a stylised representation of the reality they intend to study. However, when they are well planned and provided with robust input data and assumptions, energy models can effectively highlight critical interdependencies and trade-offs within multifaceted energy systems.

There are a variety of energy models and tools available to decision-makers. A *model* is a representation of reality or a hypothetical case, and it is formed by combining and elaborating a set of assumptions, data and information about the case under study. So, an energy model represents a specific energy system or its subset. Energy modelling *tools* are the platforms used to describe energy models, and they usually take the form of software (e.g. LEAP, OSeMOSYS, TIMES). An energy modelling tool, therefore, provides the predetermined template to input and compute the data and assumptions of an energy model. They can consequently represent an infinite number of energy models.

Classification of energy models

There is no official taxonomy of energy models in the literature. Figure 2 proposes a simplified classification of energy-related models derived from Rogner (2017) and Machado et al. (2020). Two are the main categories: “traditional” energy models, whose key objective is to study different aspects of energy demand and supply in the energy system, and energy-economy models, which model the interplay between energy and other economic sectors and aspects.

Figure 2. Simplified classification of energy models



Source: Author's elaboration from Rogner, 2017 and Machado, et al., 2020.

We find three sub-categories of **traditional energy models** according to their primary aim. **Optimisation models** seek to provide normative models of the optimal technology set to accomplish a defined target under particular constraints. The term "optimal" is often taken to mean the most cost-effective option, but that is not always the case (for example 'optimisation' could refer also to maximising energy access). Within this category we find *electricity dispatch models* that simulate energy demand-supply requirements at a high frequency, e.g. hourly, to determine the optimal mix of energy resources to be dispatched. We also find *least-cost geospatial electrification models* that answer the question of the cheapest technology to expand electricity access to the next "node" of energy users in a specific location. Unlike optimisation models, **simulation models** are not prescriptive but rather predictive. Their main objective is to generate forecasts or predictions of the evolution of the energy system at a defined geographic level, e.g. a country or region, for a given set of assumptions. They often answer the question: "How will the energy system of country X evolve over the next Y years in scenarios A, B, and C?". Finally, a number of **mixed models** bring together predictive and prescriptive aspects related to energy systems and often serve to explore the "optimal" future energy system for achieving a determined goal. The key research question they usually answer is: "What are the effects of different scenarios of policies/decisions on the future energy system and related environmental issues (e.g. greenhouse gas (GHG) reductions, climate change impacts)?". Table 1 provides a non-exhaustive list of popular energy modelling tools for each energy model category.

Table 1. Overview of main energy models and tools

Model family	Tools	Primary focus
Optimisation models	MARKAL, TIMES, MODEST, PERSEUS, IKARUS, GAINS, *OnSSET, EPM/GAMS, PLEXOS*	Normative scenarios
Simulation models	LEAP, MESSAGE, PRIMES, POLES, NEMS, WITCH, MESAP, GEM-E3, GCAM, EnergyPLAN, STREAM, SimREN, MiniCAM, GTEM, E3MG, BALMOREL, *MAED, LDF*	Forecasts, predictions
Mixed models	OSeMOSYS, MERGE, INVERT, IMAGE, H2RES, FUND, EnerGis, EMINENT, DECC, CIMS, BREHOMES, BREDEM, *WASP, CLEWs*	Exploratory scenarios

Source: Machado, et al., 2020 (tools in *italics* have been added by the author)

Traditional energy models are *partial equilibrium models*, which means they treat additional economic markets as pre-specified inputs without considering the feedback loops that changes in the energy system can have on these markets or the overall economy. For example, in energy system models, the demand for energy services (heating, cooking, lighting etc.) is fixed, and the model will then compute the characteristics of the energy supply to balance the pre-specified demand. However, the model will not describe how changes in that balance will influence demand or economic growth.

Energy-economy models seek to investigate the links between energy and the economy. A recent EEG Energy Insight paper (Klooss, 2022) provides an overview of energy-economy modelling approaches. One option is to introduce a **"soft link"** between an energy model with a macroeconomic model. In this case, the macroeconomy is described through a statistically-rich **input-output (IO) model**, representing the economic activity in different sectors, international trade, population (and potentially even income levels, urban/rural splits, occupation, skills levels, etc.). Next to it, an energy system model of the same geographic area is developed. The two models are then linked exogenously by imposing the output of the energy model for a determined future scenario as an input of the IO model. In this way, the macroeconomic consequences of different energy scenarios can be studied. However, this is still a partial equilibrium approach as there is no automatic loop between energy and the economy. This can be resolved by **Computable General Equilibrium (CGE) models**. These models endogenously integrate the energy and economic systems, including the different feedback loops between the two. These are generally complex models that meticulously describe the economy through variables of elasticities, i.e. the assumptions of how changes in price and other economic parameters influence the demand for goods and services (including energy). Rather than being built bottom-up through technology-rich data, CGE models are built top-down by specifying the statistically elaborated relationships between the price (or cost) of inputs and their demand (price elasticity), the demand for other inputs (cross-price elasticity), levels of income (income elasticity) and the link with other economic variables. In this way, a change in an energy variable may affect certain economic variables that, in turn, may influence the demand for energy services, and the automatic energy-economy loop is established.

As in everything, there are trade-offs to be considered between using an IO and a CGE model. For instance, top-down CGE models can predict the effect of energy-related policies (e.g. limit on carbon emissions, a certain price of carbon) on different economic sectors, commodity prices and the consequent shifts in energy demand. They can be interfaced with artificial intelligence and machine learning to provide sophisticated analyses of energy-economy links. However, CGE models require granular statistical data to define realistic elasticity coefficients that can be missing in developing countries or for new technologies. Moreover, "such models can easily become 'black boxes', with every optimisation occurring within the model and little ability to interrogate the overall driving factors or levers that policymakers need to consider" (Klooss, 2022). On the other hand, soft-link energy-economy models may require effort in exogenously producing the feedback loops between the energy policies, economic growth and energy demand. Still, the intrinsic need for such "human intervention" makes these models' results more interrogable and transparent.

3. EEG research on energy modelling

Due to the importance of energy modelling in supporting evidence-based policy and decision-making, EEG funded several research and capacity-building initiatives that used and/or researched modelling approaches and tools. Table 2 lists all energy modelling-related activities funded by EEG. Below it, the paper highlights the key contributions of the EEG-funded energy modelling activities to addressing the four key strategic energy planning challenges of developing countries, namely a) long-term energy system forecasting and optimisation, b) optimisation of electrification strategies, c) optimisation of short-term electricity balancing and dispatch, and d) studying the nexus between energy, economy, and broader resource constraints. For simplicity, the first column of Table 2 assigns reference names to each project that are then used when referring to these activities throughout the remainder of this section.

Table 2. Summary table of EEG activities involving energy modelling

Project reference	Project name	Implementers	Countries	Model family	Tools used
CCG	A techno-economic and financial analysis of a Gulf-India undersea electricity interconnector	Climate Compatible Growth (CCG) Programme, Oxford University, KTH Royal Institute of Technology, Loughborough University, Imperial College London	Gulf Cooperation Council (GCC) countries, India	Mixed models	OSeMOSYS
ESMAP	Planning for dispatch efficiency. Using health checks to ensure efficiency, reduce costs and ramp up renewable energy use	World Bank Energy Sector Management Assistance Program (ESMAP), Pakistan's National Power Control Center (NPCC)	Nigeria, Pakistan	Optimisation models	EPM/GAMS, PLEXOS
IRADe	Declining renewable energy costs and regional power trade in South Asia. Implications of declining costs of solar, wind, and storage technologies on regional power trade in South Asia (BBIN countries)	Integrated Research and Action for Development (IRADe)	India, Bangladesh, Nepal, Bhutan	Optimisation models	TIMES
KTH	Energy systems planning for achievement of sustainable development goals. National energy planning and policy support for the achievement of Sustainable Development Goals	KTH Royal Institute of Technology, University of Addis Ababa, Ethiopian Ministry of Water, Irrigation and Electricity, University of Sierra Leone, Ministry of Energy of Sierra Leone, Makarere University, Ugandan Ministry of Energy and Mineral Development	Afghanistan, Ethiopia, Sierra Leone, Uganda	Optimisation and Mixed models	OnSSET, OSeMOSYS, CLEWs
MIT	How probabilistic electricity demand forecasts can expedite universal access to clean and reliable electricity	Massachusetts Institute of Technology (MIT)	N/A	Simulation models	LDF, machine learning
PSI	Impacts and drivers of policies for electricity access. Micro- and macro-economic analysis of Ethiopia's tariff reform	Policy Studies Institute (PSI), Addis Ababa University (AAU), Ministry of Water, Irrigation and Energy (MoWIE), Ethiopian Electric Utility (EEU), Duke University, Sustainable Energy Transitions Initiative (SETI), University College Dublin, School of Economics and Energy Institute, University College London (UCL), World Bank	Ethiopia	CGE models	Microsoft Excel
Roundtable Initiative	Roundtable Initiative on Strategic Energy Planning	EEG as Secretariat with 21 formally endorsing organisations and over 40 participating organisations	All developing countries	All	Tool-agnostic
RWI	Electricity demand forecasting in agriculture. Harvesting the synergies of machine learning and survey data for electrification planning in Ethiopia	RWI Leibniz Institute for Economic Research, University of Massachusetts-Amherst (UMass), Policy Studies Institute (PSI)	Ethiopia	Optimisation models	GIS, Machine learning
UCL-IEEUganda	Improving energy efficiency among SMEs in Uganda. Institutionalisation of energy efficiency in Uganda: An evidence-based multi--stakeholder approach (IEEUganda)	University College London (UCL), Uganda Cleaner Production Centre (UCPC)	Uganda	Simulation models	LEAP
UCL-PATHWAYS	Energy system development pathways for Ethiopia (PATHWAYS)	University College London (UCL), Addis Ababa Institute of Technology (AAiT), Policy Studies Institute (PSI), KTH Royal Institute of Technology	Ethiopia	Optimisation and Mixed models	OnSSET, OSeMOSYS, LEAP
UCSB-REDS	Renewable energy in Southern Africa (REDS). Accelerating large-scale renewable energy deployment in Southern Africa by bridging analysis and application through decision-support tools. Renewable energy decision support tools and optimal energy pathways for Southern Africa (expansion of REDS)	University of California Santa Barbara (UCSB), SADC Centre for Renewable Energy and Energy Efficiency (SACREEE), Regional Electricity Regulators Association of Southern Africa (RERA)	Southern Africa	Optimisation and Mixed models	MapRE, GridPath, VIC-Res-Southern-Africa

Long-term energy system forecasting and optimisation

One of the main ways in which energy models are used is to shed light on the possible long-term development pathways of energy systems, for example to plan for the optimal technological mix and pace of capacity expansion to balance future trends in demand. Several EEG projects applied energy system forecasting and optimisation models to foster the long-term strategic planning in developing countries.

The KTH project aimed at closing the energy modelling capacity gaps in Afghanistan, Ethiopia, Sierra Leone and Uganda by partnering with national government officials and academics, training them in the use of open source energy planning tools such as the Open-Source Electrification Toolkit (OnSSET), the Open-Source energy Modelling System (OSeMOSYS), and the integrated Climate, Land-use, Energy, Water strategies (CLEWs/OSiMOSYS) framework, assisting them in using energy modelling to prepare evidence-based policy briefs for their national governments and further training others in their countries. OSeMOSYS was the tool used to investigate crucial policy-relevant questions such as: a) **the amount of investment needed and the optimal energy mix required for Sierra Leone to meet the SDG 7** (Sesay, et al., 2020), and b) **the effects of the variability in reservoir inflow on the Grand Ethiopian Renaissance Dam (GERD) hydropower generation** (Walle, et al., 2020). Besides the policy insights produced by the project, the emphasis should be placed on how they were produced: the project's goal was to enrich the overall national energy planning "ecosystem" using in-depth training of local researchers and government officials to sustainably bridge the capacity gap in developing, using and updating energy models. This meant that the policy insights were directly developed by locals and peer-reviewed by international experts, thus fostering the relevance of the knowledge and data used in the models and their local ownership and buy-in by policymakers.

The open-source OSeMOSYS was also the tool of choice for the CCG project. This was a co-funded initiative between EEG and its "sister programme", the UK-funded Climate Compatible Growth (CCG) programme. The modelling project looked at the techno-economic and financial feasibility of an underwater electricity interconnector between Gulf Cooperation Council (GCC) countries in the Middle East and India. A techno-economic model of a hypothetical combined India-GCC power system was developed using OSeMOSYS through which 75 scenarios covering a range of cost variables and solar PV locations in the GCC countries were analysed. The study was able to determine that **a GCC-India interconnector makes a techno-economic sense in 64 out of 75 scenarios, while the financial case for it is less definite**: of the projections developed for the scenarios from the technoeconomic model, only a small number are immediately investible and, out of the options studied, a smaller interconnector appears to be more financially attractive for investors, considering the trade-off in total system cost reductions (Shivakumar, et al., 2022).

The UCL-PATHWAYS project used the OSeMOSYS tool for participatory scenario-building to develop a long-term energy system model of Ethiopia to the year 2065. The aim was to **identify the least-cost energy supply development pathways to meet the country's universal energy access goals**. The insights from the modelling (Pappis, et al., 2021; Broad, et al., 2021; Hassen, et al., 2021; Usher, et al., 2021; Usher, et al., 2021) show that Ethiopia's substantial hydropower potential is fully exploited in the long-term and intermittent renewable energy such as solar PV and concentrated solar power (CSP) technologies would become the dominant resource for electricity generation in the country by 2065. OSeMOSYS was also used to **determine the impacts of the introduction of Minimum Energy Performance Standards (MEPS) on the national long-term energy pathways**. Interestingly, the key data inputs for the exercise came from the results of using the Low Emissions Analysis Platform (LEAP) tool to explore the potential energy savings in different phase-in scenarios of MEPS for residential appliances by 2030. LEAP showed a potential 30% cumulative energy saving on residential electricity use by 2065.

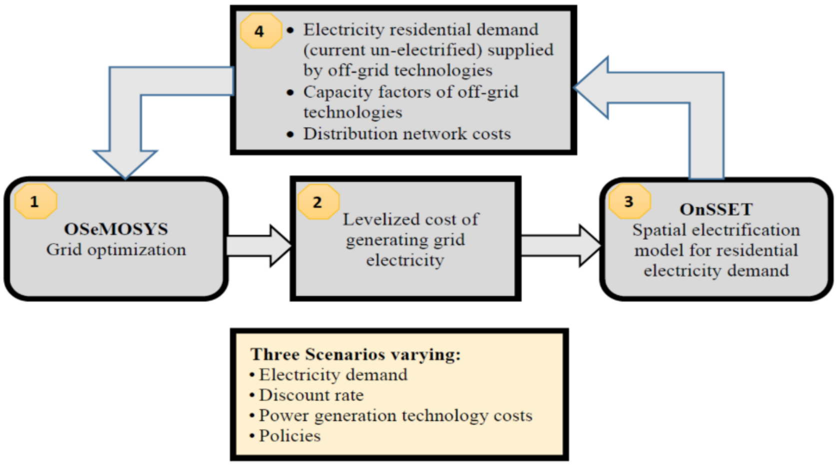
A similar approach of linking outputs and inputs of different modelling tools was applied by the UCSB-REDS project. The team used open-source modelling and multi-criteria analysis tools to **investigate the cost-optimal investments in generation, storage, and inter-regional transmission in Southern Africa under different techno-economic, structural, and climate policy scenarios**. The project sought to map barriers to renewable energy development in power system planning, identify and prioritise potential renewable energy project areas in the twelve countries of the Southern African Power Pool (SAPP), and examine the impacts of climate change and environmental and social considerations on optimal energy pathways in Southern Africa. The framework uniquely **linked three open-source models** that represent renewable resources with high spatio-temporal detail. First, the project utilised the geospatial modelling tool GridPath to produce a detailed electricity system model for SAPP countries, including high spatial and temporal resolution of wind, solar, and hydropower generation data under different economic and technical constraints. Second, to characterise the supply of renewable generation for GridPath, the project developed a renewable energy resource assessment model (MapRE) capturing the spatial diversity and temporal variability of wind and solar resources. Third, the team developed VIC-Res-Southern-Africa, a process-based hydrological-water management model simulating daily river discharge and hydropower production across all existing and planned hydropower plants in the SAPP region. In this case, energy modelling helped identify critical policy-relevant conclusions such as: 1) If technology and fossil fuel costs follow anticipated trends, wind and solar PV technologies are likely to cost-competitively dominate future electricity generation investments in Southern Africa; 2) No new coal capacity is economical in any of the twelve SAPP countries, except when inter-regional transmission capacity is constrained; 3) Less than half of all planned hydropower capacity by 2040 is needed in all scenarios; 4) Considering environmental and social siting criteria results in minor cost increases; 5) Cutting GHG emissions of the SAPP region in half by 2040 will only cost USD 9 billion over 20 years (Chowdhury, et al., 2022).

Optimisation of electrification strategies

Due to the SDG goal of delivering universal access to energy by 2030, energy modelling in developing countries often focusses on supporting the optimisation of the electrification expansion efforts, ideally by facilitating the integration of substantial renewable energy sources. Indeed several EEG-funded projects focused on enhancing the strategic planning of electrification, particularly in Africa.

A notable approach was used by the UCL-PATHWAYS project, which applied the OnSSET modelling tool to determine the **least-cost electrification setups to reach Ethiopia's goal of universal energy access by 2025**. OnSSET is an open-source and open-access Geographical Information System (GIS)-based optimisation tool developed to support electrification planning and decision making for the achievement of energy access goals in currently unserved locations. The innovative approach introduced a **soft link between the national energy system developed in OSeMOSYS with OnSSET** (Figure 3) (Pappis, et al., 2021). This allowed the OSeMOSYS model to be used to feed a more accurate levelized cost of grid electricity into OnSSET to identify the least-cost geospatial electrification pathways (grid vs. mini-grid vs. off-grid) to achieve the national goal. OnSSET also allowed modellers to calculate the transmission and distribution costs for grid expansion per kW of new generation capacity, capacity factors for the off-grid technologies identified (based on local energy resource characteristics at off-grid locations), and the demand split between grid- and off-grid technologies for the country, which were used as input data for the OSeMOSYS model again, to start another iteration of the process. The iterations around the process delineated in Figure 3 continued until reaching a point where the average cost of generating electricity in each scenario did not change after each iteration. The resulting OnSSET modelling shows that **hundreds of additional mini-grids will be required through to 2070, particularly for regions in Ethiopia's southeast**.

Figure 3. Overview of soft-linking the OSeMOSYS model with the OnSSET model used by UCL-PATHWAYS



Source : Pappis, et al., 2021, p. 8

OnSSET was also used by researchers from Kabul Polytechnic University and the Ugandan Ministry of Energy and Mineral Development trained by the KTH project to develop the **least-cost electrification pathways for Afghanistan and Uganda, respectively, to meet national SDG 7 goals** (Korkovelos , et al., 2020) (Basudde, 2020).

A geospatial model was also chosen by the RWI project, which sought to **provide policy insights into the optimal electrification pathways for Ethiopia to enhance agriculture productivity**. The project used machine learning techniques to enhance the process of identifying existing diesel engine-powered irrigation pumps from satellite images (through a combination of identifying the pollution from diesel engines and differences in vegetation between irrigated and unirrigated plots). This approach was supplemented by ground truthing exercises via community surveys that allowed the machine learning to be further calibrated or "trained" to improve its accuracy in identifying the location of irrigation plots using diesel-powered pumps. The underpinning rationale for this research was that providing electricity access to these plots would lower cost of energy used in irrigation, thus which in turn would both further promote the productive use of energy and lead higher economic and societal co-benefits. The research found that the project's model was able to correctly identify the existence of a diesel-powered irrigation plot in 75% of cases (Lukuyu, et al., 2022).

The original research was carried out using satellite images for pollution data that were at a spatial resolution of 7 by 3.5 km measured nearly every day, while the crop cover satellite imagery was at a spatial resolution of 250 by 250 m^2, collected every 16 days. and the crop cover satellite imagery at a spatial resolution of 250 by 250 m2, collected every 16 days. Though the study showed promising results, the limited ground-truth sample size collected, and the nature of the publicly available satellite data used made it difficult to generalize findings beyond the study region of Amhara. The research team suggested the use of satellite imagery with a higher spatio-temporal resolution would further improve the accuracy of the technique and make better use of relatively expensive ground-truthing exercises. The approach could potentially reduce the cost of developing least cost electrification models for productive use applications in agriculture (Lukuyu, et al., 2022). .

Machine learning enhancement of GIS-based modelling was also addressed by the MIT state-of-knowledge paper on the **use of probabilistic electricity demand forecasting compared to the more common point-based forecasting** (Lee, et al., 2021). The paper used the lightweight data fusion (LDF) model previously developed by the same team (Dean, et al., 2020) as a case study to showcase the benefits of probabilistic electricity demand forecasting. The model combines the interpretability of probabilistic graphical models (PGMs) with the flexibility and expressiveness of neural networks (NNs) to allow data fusion, which is particularly useful in developing countries' contexts where different and unrelated data (survey, satellite imagery, statistics, GIS layers of known infrastructure locations etc.) have to be used. The paper concluded that main advantages of using probabilistic modelling in demand forecasting are: a) the ability to better understand energy demand uncertainty, hence enabling risk-averse decision-makers to target balanced levels of renewables and fossil-derived generation investment over time, so improving risk management in meeting emissions targets while seeking to maximise economic efficiency and growth; b) enabling real options analysis, for example in deciding the optimal amount and timing of investment strategies in more expensive upfront grid-compatible mini-grids based on the probability that high demand will eventually warrant connection to the main grid (Lee, et al., 2021).

Optimisation of short-term electricity balancing and dispatch

Energy planning does not only involve long-term energy development strategies. The study of how to optimise the short-term dispatch of electricity is equally important and can save millions of dollars in avoided overcapacity and reliability of the energy supply. Electricity dispatch models are often used to estimate the demand-supply requirements throughout the day to optimise the integration of different energy supply and storage technologies, including the simulation of the best balance of import and export of electricity.

The IRADe project used the least-cost optimisation tool TIMES to develop an integrated electricity model of Bangladesh, Bhutan, India, and Nepal to predict the optimal hourly power trade under different scenarios. The scenario-based assessment helped answer questions on the **impact of the declining cost of solar, wind, and storage technologies on regional power trade; the implications for regional hydro potential; the effect on capacity requirements; the possible capacity mix in the region; and environmental benefits in terms of lower CO_2 emissions**. Policy-relevant insights from the scenario analysis included: a) regional power trade can help Nepal and Bhutan to triple the utilisation of their untapped hydropower potential by 2045; b) a high cost decline of renewable energy and energy storage technologies would have a substantial impact on the optimal regional power trade dynamics in the region by 2050, with Bhutan potentially increasing its power exports 20-fold, while India and Nepal would move from being net importers to net exporters, and Bangladesh would increase its regional power importation by over 20 times; c) the massive increase in electricity imports (mainly renewable-generated) by Bangladesh would allow a 97% annual reduction in that country's CO_2 emissions by 2050 compared to the baseline scenario (Parikh, et al., 2022).

The ESMAP project conducted an electricity dispatch optimisation study in Pakistan and Nigeria to **explore ways to reduce operating costs and introduce system flexibility to ramp up variable renewable energy generation without jeopardising system reliability**. They used the World Bank's Electricity Planning Model (EPM) implemented in the General Algebraic Modelling System (GAMS) to model dispatch optimisation and compared the results with the actual dispatch in both countries to identify critical efficiencies to be applied. The modelling exercise surfaced significant potential savings in both cases: 1) In Nigeria, the combined annual benefits from operational and commercial improvements identified through energy modelling could have saved 579 million USD in 2018 or a 29% reduction in total annual costs (Remy & Chattopadhyay, 2021); 2) In Pakistan, a dispatch regime based on the modelled optimum would have resulted in a 17.8% cost reduction, which is equivalent to a savings of 1,032 million USD (World Bank, 2020).

Studying the nexus between energy, economy, and broader resource constraints

EEG energy modelling activities did not only study energy systems in isolation. Energy policies can have substantial economic, environmental and social impacts, and energy models can help crystallise them.

As mentioned in Section 0, energy-economy models can simulate the impacts of energy policies on other economic sectors and vice versa. For instance, the PSI project used a CGE model to assess the **impacts that different uses of the increased revenue from raising power tariffs in Ethiopia would have on the electricity demand of households and commercial consumers (micro-economy), and on the broader economy (macro-economy).** Ethiopia has one of the lowest electricity tariffs in Africa and the Government resolved to embark on tariff reform, changing the way in which it was calculated and phasing in increases over four consecutive years from 2018. The project aimed to provide policy insights for the Ethiopian regulator and government on the potential economic impact of this on-going national electricity tariff reform. The modelling exercise simulated two cases in which the additional revenue generated from the increased electricity tariff is (i) indirectly collected by government to compensate for subsidies in the sector, and (ii) recycled to investment. The findings were that, over the limited study period of four years, “the revenues generated through the tariff hike are not enough to offset the negative economy-wide impacts caused by the increased electricity price in the short-run because the price shocks are too large, and the economy needs a long-time to adjust. As a result, the electricity tariff reform would cause a reduction in GDP and household’s aggregate consumption” (Timilsina, et al., 2022).

While linking energy and economic models is a common way to identify the broader linkages between energy and the overall economy, sometimes the modelling process itself can become the means for exploring such interdependencies. For example, the UCL-IEE Uganda project utilised a multi-stakeholder participatory approach to building fit-for-purpose long-term energy scenarios for Uganda using the LEAP modelling tool. The model focused on two of the most energy-intensive industries, cement and iron and steel, which are essential for job creation, infrastructure development, and technological growth. The innovative trait of the modelling effort was the **use of LEAP as a platform for policy dialogue and deliberation between SMEs, the government, and academia to define long-term scenarios of energy efficiency penetration, discuss their energy, economic, environmental and social implications**, **and explore the most appropriate course of action for the government and the industry.**

Finally, exploitation of energy resources may be linked to, and sometimes even in competition with, other environmental systems such as land, water and climate. Integrated resource modelling is a method that allows analysing the interdependencies between different resources. The KTH project used the open-source Climate, Land, Energy and Water systems (CLEWs) modelling tool to **investigate the integrated impacts of Ugandan strategy to shift from biomass to electricity consumption on deforestation, long-term electricity supply infrastructure, crop production, water consumption, land-use change and GHG trajectories**. All four resource systems were modelled through a modified version of the OSeMOSYS tool to include data on land cover, land-use, demand for public water supply, and crop production. The model then optimised the strategy for resource supply, transformation and use to meet the annual energy, water and agricultural crop demands until 2050. The integrated modelling analysis published in an open access paper (Sridharan, et al., 2020) showed how a policy change in one resource system has ripple effects on other interlinked systems that can lead to effects that are incoherent with the original objectives of the policy change. For instance, in the case of Uganda, shifting from biomass to electricity as an energy source may lead to increased electricity costs, which could lead in turn to changes in agricultural practices. It is therefore imperative to analyse and consider such cross-sectoral links during policy formulation.

4. The Roundtable’s Key Strategic Energy Planning Principles and the U4RIA goals

Through its extensive interactions with national energy planners through the above modelling projects, EEG and its partners developed an understanding of some of the shortfalls in Development Partner (DP) historical endeavours to support strategic energy planning in developing countries. These include:

1. Support for energy planning is often externally driven, in that it typically originates from the broader agendas of DPs and is then usually delivered through international consultants. In such cases, national stakeholders are generally involved in requesting data and information, but they are rarely empowered as partners and custodians of that part of the energy planning process. Models and tools used can remain ‘black boxes’, meaning analyses lack transparency and cannot be replicated, updated, or tailored in the future, or even peer reviewed.
2. Support is often fragmented, as these efforts are usually concentrated on the specific aspects of a national energy system that are of interest to the DPs or researchers involved.
3. Support is often uncoordinated, with multiple studies driven by different actors and agendas, resulting in duplications of effort and inefficient use of resources.

4. Where energy planning support has included national capacity building activity, it is typically ad hoc or short-term in nature.

Energy modelling outputs developed under this approach often result in a lack of buy-in by national policymakers and other energy stakeholders and lead to very little improvement in national capacity to improve or update the resulting energy plans over time, without resort to further expensive external support.

Based on this understanding, to improve the effectiveness of the support provided to strategic energy planning in developing countries, **EEG promoted dialogues and collaborations amongst DPs, technical institutions, research organisations and consultancy firms from 2017 to 2022. This process evolved into the Roundtable Initiative on Strategic Energy Planning**. The Round Table continues on beyond the lifetime of EEG and is now hosted by a sister FCDO-funded research programme - Climate Compatible Growth (CCG). The Roundtable focuses on four areas:

1. harmonised engagement,
2. capacity building through co-development,
3. community platforms for data and tools accessibility, and
4. data, models and standards.

To promote a more harmonised approach, the Roundtable process developed a set of **'Key principles for improving the support to strategic energy planning in developing and emerging economies'** (Roundtable Initiative, et al., 2021 – hereafter referred to as 'the Roundtable Principles'). The five principles relate to:

> **National ownership.** Support country-led energy planning processes that work in partnership with key stakeholders[1] to achieve broad consensus on strategic objectives and plans. Help empower the relevant authorities at regional, national, and subnational levels to rally stakeholders to implement the plan and push back on proposals that do not align.
>
> **Coherence and inclusivity.** Assist Governments to ensure that strategic decisions taken in the energy sector are coherent with broader economic, social, and environmental goals (including Sustainable Development Goals and Nationally Determined Contributions under the Paris climate change agreement) by committing to evidence-based, integrated and inclusive energy planning processes that lead to fair and technically sound energy development programmes.
>
> **Capacity.** Support Governments in the definition of priority capacity building activities which strengthen the capability of national institutions to take the lead on strategic energy planning and incorporate plans and evidence into decision-making and implementation processes. Commit to the coordination of Development Partners in line with the Government's vision, requests for support and goals, and avoid fragmentation and duplication of efforts.
>
> **Robustness.** Promote the use of models, analysis and decision-support tools that have strong technical and economic foundations, are fit-for-purpose to deal with rapidly changing circumstances in the energy sector, are able to support flexible and adaptive approaches to energy sector planning and can be easily and regularly updated.
>
> **Transparency and accessibility.** Promote open access to and review of planning inputs (data, model design and assumptions) and encourage the accessibility of planning outputs to key stakeholders, subject to government restrictions and commercial confidentiality constraints.

The Roundtable Principles are a "code of conduct" for DPs to work collectively towards improved effectiveness of their support to country governments on strategic energy system planning. To date,

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[1] Key stakeholders are defined as governments, government agencies, consumers/citizens and civil society organisations, utilities, investors, project developers and international development partners.

twenty-one high-profile organisations[2] have already endorsed the Roundtable Principles. Their application is important to move away from the externally driven, uncoordinated, and opaque support described above and towards the development and nurturing of a self-sustained national energy planning ecosystem, that is nationally owned and based on transparent and accessible evidence. **As an example of how these principles might apply in practice, the performance of EEG energy modelling projects is assessed against them in Annex 1.**

In addition to the Principles, to further foster the transparency and accessibility of energy modelling data, processes and tools, the Roundtable partners, under the guidance of EEG and CCG, also developed the U4RIA goals. U4RIA stands for Ubuntu (community), Retrievability, Reusability, Repeatability, Reconstructability, Interoperability, and Auditability. They are a series of goals – with the ambition to become standards – for good, transparent and accessible energy data modelling and management, jointly developed by multiple organisations involved in the Roundtable Initiative. A public forum to further develop and improve the U4RIA goals was set up by EEG and CCG and an open access research paper was co-authored to better define and describe the U4RIA goals is available in preprint version (Howells, et al., 2021). The paper uses the case of Costa Rica, which has a very open national energy planning process based on transparent data and workflows.

5. Key lessons and knowledge gaps for future research

Key lessons from the above EEG research

This section considers the key lessons drawn from the EEG-funded energy modelling activities described above and the knowledge gaps that remain to be filled by future energy modelling-based research. This section draws on a paper (Klooss, 2022) summarising the outcomes of an EEG 3-part webinar series from 2021 that sought to identify lessons from the relevant EEG projects around three research questions:

1. does energy modelling enhance policy making?
2. how can models best address energy sector challenges?
3. what are the frontiers of energy modelling?

The resulting findings from the workshops can be summarised as follows:

- **National or end-user ownership of models is key for longevity.** The examples from the policy insights provided by the EEG energy modelling activities showcase the potential impact that energy modelling can have to steer strategic energy planning in developing countries to meet SDG 7 and other national goals. However, models are only the means to crystallise future scenarios, policy options and trade-offs. Energy modelling needs to be at the service of a nationally driven energy planning process, not vice versa. It is then imperative to move away from the fragmented and externally led support and instead foster the **national ownership** of the energy modelling and planning process, so that it can suit the national priorities.

- **Data access and transparency matter for impact and are critical for national ownership.** Models are only as good as their actual impact on evidence-based policies and decision-making. To be

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[2] Agence Française de Développement (AFD), African Development Bank (AfDB), Applied Research Programme on Climate Compatible Growth (CCG), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Applied Research Programme on Energy and Economic Growth (EEG), Applied Research Programme on Energy and Economic Growth (EEG), World Bank – Energy Sector Management Assistance Program (ESMAP), Fondazione Eni Enrico Mattei (FEEM), United Kingdom – Foreign, Commonwealth & Development Office (FCDO), Institut du Développement Durable et des Relations Internationales (IDDRI), International Renewable Energy Agency (IRENA), Swedish Royal Institute of Technology (KTH), Open Tools, Integrated Modelling and Upskilling for Sustainable Development Community of Practice (OpTIMUS), Netherlands – Environmental Assessment Agency (PBL), Politecnico di Milano, Regional Center for Renewable Energy and Energy Efficiency (RCREEE), Stockholm Environment Institute (SEI), The Bartlett Energy Institute – University College London (UCL), United Nations Development Programme (UNDP), United Nations Economic Commission for Africa (UNECA), United Nations Institute for Economic Development and Planning (UNIDEP), World Resources Institute (WRI).

nationally owned and utilised in decision making, models need to be as transparent as possible. The **U4RIA goals** provide a set of goals that can be used by modellers as standards to improve the transparency and accessibility of their data, analyses and tools. The Roundtable Initiative referenced above produced a template to be used in Terms of Reference when contracting technical support for modelling, to embed the U4RIA principles in a practical way in strategic energy planning practice[3]. This template provides guidance on how *Ubunbtu (community engagement)* can be ensured by including peer review processes, stakeholder engagement and consultations, as well as properly crafted capacity building activities. Likewise it embeds *Retrievability* through reference to the publication in open access platforms of the data and deliverables, and the clear attribution of the deliverables so that the authors can be contacted. *Repeatability* is fostered by the use of a comprehensive and set of metadata. *Reusability* of models is strengthened by building on previous models and studies available, and releasing modelling outputs in machine-readable, non-proprietary open file format complying with the Open Definition. *Reconstructability* is supported by a clear description of the workflows to move from the modelling input to the output data, so that the process to obtain the output can be reconstructed by a third party. *Interoperability* is sought through delivering the output data in forms that are conducive for their utilisation by other models with minimal manipulation. And *Auditability* is enabled by the transparency and accessibility derived from following the other goals, and U4RIA-compliance audits can be foreseen.

- **Models and tools can make a real difference for planning and decision-making – but this requires clarity of purpose and coherence with the energy system planning.** Energy modelling approaches and tools are not all the same and are, instead, each best fit to answer different policy questions and needs (see Table 1). CGE models are exceptionally fit for answering questions on the links between energy policies and trends in the economy, but they would not work as well in determining long-term energy system scenarios, let alone the optimal electricity dispatch patterns. Therefore, modellers need to be guided by clear and locally relevant policy questions to design energy models that are **robust and fit-for-purpose**. At the same time, as shown in the examples from section 3, due to the complexity of strategic energy planning (see Figure 1), the policy impact of energy models is enhanced when they are accurately combined (or "linked") to address system-level questions or highlight complex interlinkages in the energy system. This was, for instance, the case of the soft links between OnSSET and OSeMOSYS in the UCL-PATHWAYS project, GridPath and MapRE in the UCSB-REDS project, and OSeMOSYS and CLEWs in the KTH project. By linking different modelling tools and approaches together, these hybrid methodologies can have the ability to compensate for the trade-offs and limitations of certain models and enhance the **coherence** of the overall energy planning process.

- **Novel modelling approaches enhance the realm of the possible.** Several EEG-funded activities used machine learning to "train" models to recognise patterns or interdependencies, thus enhancing their **robustness**. For instance, the RWI project used machine learning classifications to refine the correspondence between irrigation seasons, seasonal variability of pollution and crop cover datasets to model the location of diesel-powered irrigation activity in Ethiopia, based on publicly available data alone (Lukuyu, et al., 2022). The MIT knowledge paper also showcased the benefits of probabilistic machine learning forecasts in dealing with the uncertainty behind energy infrastructure investments (Lee, et al., 2021). As Klooss (2022) put it, "artificial intelligence and machine learning remove boundaries of quantity and type of data, allowing the input [in energy models] of any quantitative or non-numerical as well as visual (e.g. satellite imagery) data". This is especially important to tackle the data paucity in developing country contexts. Another welcome trend in energy modelling approaches is the inclusion of "soft factors", such as social, political and environmental considerations (as seen for example in the UCSB-REDS, KTH, UCL-IEE Uganda, and

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[3] The document is not public yet. To request a copy, please write to the corresponding author.

PSI projects). These multi-criteria and nexus-based modelling approaches can improve the **inclusivity** of strategic energy planning.

- **The tools exist – capacity is needed to select and tailor them.** This paper illustrates multiple energy modelling approaches that can be appropriate to answer a wide range of policy questions, including very complex ones. However, the capacity to properly design, implement, communicate, and update energy models is still lacking in many developing countries. The tendency to outsource modelling activities and research to organisations from the Global North is still in place. This is not inherently a problem because it may guarantee best-in-class modelling practices are applied, but it is not a sustainable strategy in the longer-term. A different approach involving a long-term **capacity** development vision for all the different energy stakeholders (government, utilities, academics, students, financial institutions, civil society etc.) is required to shift from externally- to nationally driven energy planning. The inclusion of in-depth and hands-on training activities, long-term backstopping support, higher education curricula creation, training-of-trainers and other efforts to develop the capacity of local communities of energy modellers and planners needs to become the norm of international support for strategic energy planning.

Areas for further research

Based on the above work, a number of areas for further research work emerge:

1. What are the most effective ways of building, embedding, and supporting modelling capabilities in national governments and institutions and what capabilities should be prioritised?
2. Where new modelling approaches are demonstrated to have significant potential for use in developing country context but require access to, for example, satellite-generated data or very high levels of computation power for running models or machine learning, what is the best way of facilitating access to such technology for national modellers and policy makers?
3. Addendum for contracts has been suggested as one way of embedding improved practice such as the U4RIA goals or the Roundtable Principles in DP-funded modelling activities in developing countries, but what other approaches exist to ensure national governments have access to effective support in strategic energy planning?
4. The U4RIA goals set the general principles for transparent and accessible energy modelling, but what “minimum” or “reasonable” data management and modelling practices should be part of a U4RIA standard?

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Annex 1. Application of the Key Strategic Energy Planning Principles by EEG research

In order to study the contribution of EEG-funded energy modelling activities to improving strategic energy planning in developing countries, the adherence to the Roundtable Principles by these activities have been mapped (**Error! Reference source not found.**). To do so, proxy signals of the application of the principles were defined as follows:

- **National ownership** was defined as **active involvement of local partners** and the production of documents containing **clearly communicated policy recommendations** from the energy modelling (e.g. policy briefs)
- **Coherence and inclusivity** were defined as the **fostering of coherence beyond the energy sector**, for example by looking at energy-economy linkages or the nexus with food, land, water and climate, as well as the focus on **addressing social inequalities or the use of inclusive/participatory approaches**
- **Capacity** was defined as the delivery of **direct training** and **training of trainers** so that energy modelling and planning skills are enhanced in the short and longer-term, respectively
- **Robustness** was defined as the utilisation of **theoretically-sound and fit-for-purpose models**, demonstrated, for example, through the use of widely used modelling tools and the publication of peer-reviewed articles explaining the modelling approach
- **Transparency and accessibility** were defined as the **use of open source models / tools** and the **publication of transparent data and assumptions** included.

In **Error! Reference source not found.**, a tick symbol (✓) was added every time one of these proxy signals for the Roundtable Principles was encountered in an EEG energy modelling activity to map its linkages with the principles. The MIT activity was excluded as it did not involve original modelling activities, but was rather the publication of a review of modelling activities in the literature. The results are discussed below.

EEG's general approach was one fostering national ownership of the energy planning process. As can be seen from the list of partners in Table 2, **all but two activities included local organisations in the project partnership.** The national partners included the different types of energy-related stakeholders, including energy ministries, line ministries, research institutes, universities, utilities, regulators and NGOs. In addition, although the IRADe project did not include partners, IRADe itself is a research institute based in the Global South, specifically in New Delhi, India. Notably, another project was led by a research institute from a developing country, the Policy Studies Institute of Ethiopia. Furthermore, **6 out of 9 projects involved the production of recommendations targeted to policymakers**. Most of them took the form of policy briefs (Walle, et al., 2020; Sesay, et al., 2020; Hassen, et al., 2021; Broad, et al., 2021; Hassen, et al., 2022; Beyene, et al., 2022; Lukuyu, et al., 2022; Bensch, et al., 2022; Deshmukh, et al., 2022; Usher, et al., 2021).

Table 3. EEG energy modelling activities' linkages with the Roundtable Principles

Roundtable Principles	National ownership		Coherence & inclusivity		Capacity		Robustness	Transparency & accessibility	
Specific linkages	Involved local partners	Produced policy briefs	Fostered strategic coherence beyond energy	Addressed social inequalities or used inclusive approaches	Delivered direct training	Delivered training of trainers	Robust and fit-for-purpose model	Open-source model	Transparent data and assumptions
CCG							✓	✓	✓
ESMAP	✓						✓		✓
IRADe	(✓)[a]						✓	✓	✓
KTH	✓	✓	✓	✓	✓	✓	✓	✓	✓
PSI	✓	✓	✓				✓	✓	(✓)[c]
RWI	✓	✓	✓	✓			✓	?	(✓)[c]
UCL-IEEUganda	✓	✓	✓	✓	✓		✓	(✓)[b]	
UCL-PATHWAYS	✓	✓	✓	✓	✓	✓	✓	✓	(✓)[c]
UCSB-REDS	✓	✓	✓	✓			✓	✓	✓

In addition, the UCL-IEE Uganda project embarked in a participatory multi-stakeholder policy dialogue using LEAP (see Section 3). This approach was important to close the communication gap between techno-scientific evidence and policy-making.

EEG energy modelling activities promoted coherence and inclusivity in the energy planning process. Two thirds of the projects explicitly considered the linkages of energy with other sectors or the overall economy. This was done through analyses assisted by energy-economy models (PSI), multi-stakeholder scenario building (UCL-IEE Uganda), or nexus-driven models looking at the energy linkages with climate, land, food, and water (KTH, UCL-PATHWAYS, RWI, and UCSB-REDS projects). Five energy modelling projects also addressed inclusivity aspects of strategic energy planning either by using participatory approaches (RWI, UCL-PATHWAYS, and UCL-IEE Uganda) or by providing insights on social vulnerabilities such as food security and climate resilience (KTH, RWI, and UCSB-REDS).

According to the documents analysed, the majority of EEG energy modelling projects lacked substantial capacity building components. The research uptake of these initiatives has been generally demanded to dissemination activities such as stakeholder workshops, rather than carrying out proper skill enhancement and knowledge transfer endeavours, or at least the author saw no evidence of them. The three main exceptions were the KTH, UCL-PATHWAYS, and UCL-IEE Uganda projects. The KTH project had capacity development at its centre: it sponsored researchers and officials from Afghanistan, Ethiopia, Sierra Leone and Uganda to attend two international summer schools (in which KTH taught) to learn how to use the OnSSET and OSeMOSYS modelling tools, worked closely with them to develop national models and related policy briefs, and supported the development of master's degree curricula in their local universities. For example, the trainees from the University of Sierra Leone designed and launched a course on Energy Investment Modelling to be embedded in the university's postgraduate curricula, while trainees from Makerere University launched a master's energy modelling course, and themselves trained other 6 other research assistants in the use of OSeMOSYS. Similarly, the UCL-PATHWAYS project had dedicated capacity building activities such as the creation of teaching material, energy modelling training for researchers from the Addis Ababa Institute of Technology (in which one of the trainees from the KTH project was a trainer), and the development of a course in the master's programme on Energy Demand & Supply Management formulated for professionals by the African Institute for Economic Development and Planning (IDEP). Finally, the UCL-IEE Uganda project also trained local staff from the Uganda Cleaner Production Centre in the use LEAP.

All EEG energy modelling activities used robust modelling methodologies and tools. The modelling tools used are reported in Table 2. Many of them are widely tested and used tools such as TIMES, LEAP, OSeMOSYS and others. In addition, peer-reviewed papers describing the modelling methodologies and assumptions were published for most of the projects. Using robust and fit-for-purpose models can boost the uptake of the modelling outputs and recommendations by decision-makers.

The EEG's approach to energy modelling have been promoting transparency and accessibility of the evidence, models and tools. Most energy modelling projects used open source and/or free of charge models and modelling tools. Although being open source does not inherently give an indication of the tool's robustness and applicability, the use of such models enhances the accessibility, accountability, and auditability of energy modelling. Furthermore, almost all projects have published or is in the process to publish the detailed modelling processes and assumptions applied, while 5 of them (CCG, IRADe, KTH, UCSB-REDS, and ESMAP) have published the extensive version of the input data used.

These practices fostering transparency and accessibility in energy data, models and tools represented a step forward in approaching the U4RIA goals by EEG research.

About the author

Luca Petrarulo is a consultant with 12 years' experience in international environmental projects and research, working for a variety of organisations including DFID, EC, GIZ, AFD, CDKN, UK DECC, UK FCO, and C40. His experience is multi-disciplinary, spanning from climate change to sustainable development and aid effectiveness, including some focus on energy and carbon modelling and planning. He supported EEG and now CCG in coordinating the global Roundtable Initiative on Strategic Energy Planning, bringing together major donors, development partners, and technical organisations to improve the effectiveness of their support on energy system modelling and planning to developing and emerging economies. Luca has an MSc in Environmental Change and Management from the University of Oxford, an MA in Conflict Resolution from Lancaster University, and a BA Hons in International Relations from the University of Bologna, Italy.

The views expressed in this Working Paper do not necessarily reflect the UK government's official policies.