Intelektual Journal of Energy Harvesting and Storage
Vol. 2, No. 1, 2024, pp. 30~39
ISSN: 2963-6272, DOI: 10.11591/ehs.v2i1.pp30-39

Modelling for sustainable energy transition

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Article Info

Article history:

Received May 29, 2023
Revised Apr 19, 2024
Accepted May 4, 2024

Keywords:

Bottom-up
Energy modelling
Energy models
Forecasting model
Hybrid energy system modelling
Optimization model
Top-down

ABSTRACT

Energy modelling has become important because of the global concern over greenhouse gas emissions. Governments use energy-economy models to develop climate policy. Models vary in methodology and purpose. The design of the energy transition pathways for sustainable electricity requires modelling tools that can accommodate high penetration of renewable energy sources while considering the evolution of fossil fuel sources, the cost of technology, natural dynamics of renewable sources and inherent benefits of low carbon sources like nuclear and cleaner fossil fuel technologies and other sources of energy for power generation. The study identified a wide range of models and tools with long range, short term and real time planning and decision-making capabilities. Various tools and software for modeling and optimization of grid electricity but, green smith energy management system (GEMS), modelling energy and grid services (MEGS), wien automatic system planning package (WASP), home energy management system (HEMS) showed promise for optimized real time as well as middle range grid connected energy system with a mix of renewable, variable energy sources and thermal electricity/energy sources. For use in middle as well as long range energy modeling, identified models include EnergyPLAN, model for analysis of energy demand (MAED), model for energy supply strategy alternatives and their general environmental impact (MESSAGE), and long-range energy alternatives planning system (LEAP).

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1. INTRODUCTION

Energy has significantly become an important input for the global socioeconomic transformation especially with the growth in industrial and agricultural activities [1], [2]. Energy models help in proper allocation of different available energy resources in meeting the current and future energy demand [3]. Energy systems face the challenge of adapting and evolving subject to ever changing social, economic, and environmental pressures and concerns like diminishing reserves, greenhouse gas emissions, resource supply and price fluctuations and global warming, among others [4]–[6]. There is a global commitment to limit the average temperature rise below 20 °C above the preindustrial level, with 189 countries signing the Paris Agreement in 2015 [7]. In line with the Paris Agreements, counties developed their national determined contribution (NDCs) that specify their strategies to reduce greenhouse gas emissions. To realize this, governments rely on energy models to design their climate policy measures on greenhouse gas emissions and economic outcomes at national, regional, and local levels. To select policy options, countries use models suitable for their policy initiative [7]. The design of the energy transition pathways to sustainable electricity systems demands accommodation of the variable renewables as well as other sources in controlled and limited contributions [8]. To realize this objective, it is necessary to apply energy modelling that can account for the natural dynamics of renewable energy sources like wind, solar and hydro, and the evolution of fossil fuel sources of energy like coal, gas and petroleum, price and supply fluctuations of all other feasible sources including geothermal and nuclear while taking care of sustainability issues in development and energy supply [4], [9].

Energy transition refers to the pathways applied towards transforming the world energy systems from fossil-based to zero-carbon by the second half of this century [10]. The objective of energy trsnsition is to reduce anthropogenic greenhouse gas emissions most of which are associated with the energy sector dominated by fossil fuels. It is estimated that the use of renewable energy and application of energy efficiency technologies and measures can reduce the carbon emissions by up to 90% of targeted reductions [11]. The energy transition will greatly be facilitated by information technology, smart technology and smart energy systems, policy measures, market instruments, and effective planning and optimization models [8], [12]. Therefore, the energy transition represents change in the energy systems in terms of energy supply, processing, or production, energy conversion and delivery, energy consumption, and energy markets. The energy transition has implications on the economy, society, environment, institutions and technology [11], [12]. The transition should therefore be assessed within all the important dimensions [10], [13].

Energy modeling or energy system modeling refers to the process of building computer models of energy systems to facilitate analysis [14]. Energy models often employ scenario analysis to investigate assumptions made about the technical, social, and economic conditions at play. Model outputs are usually economic feasibility, greenhouse gas emissions, financial costs, consumption of natural resources, and energy efficiency of the system under investigation. Various techniques employed, in modelling include economic and engineering. Model optimization is often employed to establish the least cost. The main objective of energy models is to contribute in various ways to system operation, design, energy policy as well as system operation [15].

Energy planning has been made a complex undertaking because of underlying unavoidable interaction coexisting between energy demand, technology advancement, economic development and growth, and sustainable development goals. Energy or electricity planning is a complex endeavor dealing with many complex variables with constraints and assumptions [16], [17]. The effect of the oil crisis of mid-1970s, led to the development of energy planning models to support policy making. These models have proved to be useful and reliable for large scale energy systems planning. The energy models can help to reflect the entire energy or electricity supply system based on detail of input data used for analysis. The models can explore the desirable or proper supply of energy at least cost price in meeting present and future energy needs. Other considerations are availability of resources, infrastructure, environmental impact, with social concerns being generally used as model constraints. The energy models or planning tools can be used to prepare a framework for testing policies and energy scenarios at different levels like national, multi-regional, and global levels [17]. The models are used as decision-support tools and among others include wien automatic system planning package (WASP), the model for energy supply systems and their general environmental impact (MESSAGE), the integrated MARKAL-EFOM system (TIMES), the long-range energy alternatives planning system (LEAP) and EnergyPLAN [16], [17].

Several studies on energy models have used MESSAGE, LEAP, IAM, OSeMOSYS, EnergyPLAN, EPPA, MARKAL, and others to develop optimal energy system planning and simulation model. For example, in Malaysia, the mixed integer linear programming (MILP) model is used in planning electricity generation with renewable energy schemes aimed at reducing carbon dioxide emissions. For the case of Romania, it is used to model an optimal power system for 2040. In North-West Europe, PLEXOS model is used to analyze the impact of integration of renewable energy on national policies. In Turkey, a generic algorithm is used to optimize the integration renewable energy sources in the long-term energy planning is optimized by applying a genetic algorithm. In Croatia, a multi-objective optimization approach is used to investigate the long-term impact of electric vehicles and integration of renewable energy resources in the country's power system [16], [17]. In Tamil Nadu state in India the LEAP model, applying baseline and greenhouse gas (GHG) mitigation scenarios and EnergyPLAN models have been used in generation expansion until 2030. For Poland optimization process based on grey wolf optimizer was combined with the EnergyPLAN model to provide alternative scenario and energy mix. For Indian case, EnergyPLAN model was used to plan for carbon electricity system for 2030 using a multi-objective assessment. EnergyPLAN can be used in several scenarios planning including business-as-usual case and many alternative scenarios involving renewable power generation. In Iran, EnergyPLAN was used in national level energy planning simulation approach meant to minimize natural gas demand in buildings. In Finland and Italy, EnergyPLAN was used in the sustainable energy transitions. In China, EnergyPLAN was used to analyze solar and wind energy installation for specific regions. EnergyPLAN can also be used to perform a dynamic simulation to model low carbon electricity generation scenarios that can integrate hydrogen energy and electric vehicles [10], [16]–[19].

Models are designed to generate different types of outputs and these outputs include system viability, carbon emissions or greenhouse emissions, cumulative financial costs, system efficiency among others. Models employ various techniques like economics and engineering. Where the objective is least cost analysis, mathematical optimization is often used. Energy models can also be employed in policy development by governments and planning institutions including business and non-governmental organizations. Models add value in different ways to the system operations, system design, and decision making processes. Predictive models often require developers to make estimates and reasonable assumptions which may or may turn out to be valid [20]. The intergovernmental panel on climate change (IPCC) asserts that mitigation of climate change requires a fundamental transformation of the energy supply system, which among others include substitution of unabated fossil fuel conversion technologies by low carbon energy alternatives [21].

In this study, different energy models and emerging issues are reviewed and include emission reduction models, energy and electricity supply and demand models, planning models, models that are based on neural networks, and fuzzy theories. The study will help energy planers, analysts, policy makers and electricity producers and utilities in the efficient delivery of their services and work.

2. TYPES OF ENERGY MODELS

Several new concepts have emerged over time in energy sectors that include energy conservation, increasing absorption of renewable energy sources, waste to energy conversion and recycling, decentralized generation, and emergence of the smart grids whose integration in the overall energy strategy requires effective energy models [3]. All modelling approaches do have a reflection of reality by use of the statistical averages, known facts, known past energy trends and several reasonable assumptions. It is however necessary to make some cutbacks and approximations during analysis of energy models [22]. Many different modelling approaches have been applied in energy and depends on factors like the target population which include policy makers, the scientific community and other research communities, energy generation and supply companies, model application i.e., data analysis, forecasting, optimization, ex post evaluation, simulation, and estimation of parameters; geographical coverage namely regional, national, multinational, the conceptual framework used in the models i.e. top-down: based on underlying economic theory, bottom-up: based on the technological focus focus/explicitness and available data or information used (e.g. available data on final energy, data on useful energy, availability of energy demand for branches in the service, transport sector, or industrial sector) [22], [23].

Models can be classified based on purpose, structure and assumptions made [24]. Models can be classified based on the following six dimensions top-down vs. bottom-up, time horizon, sector covered, optimization vs. simulation techniques used, level of aggregation and geographic coverage, trade, and leakage. Other modes of classification of models include applied mathematical techniques, level of data intensiveness, degree of complexity, and flexibility of the model [20]. Models can further be classified; specific and general application of the models, specific and general data requirements, coverage of models by sectors, the model structure: internal assumptions and external assumptions, the underlying methodology, the mathematical approach, geographical coverage of the model which can be global, regional, national coverage, local, or project specific coverage, time coverage or horizon in terms of short, medium, and long term and the approach used in analysis; as top-down versus bottom-up. Energy models may cover the electricity sector, or they may cover an entire energy system. Energy models are mostly used for different or specific scenario analysis, where a scenario is a coherent set of assumptions on a specific system under consideration by the model with new scenarios being tested against a baseline scenario also called the business-as-usual (BAU)–and the differences in outcome observed and analyzed.

3. ROLE OR APPLICATION OF MODELS

Models have generally as general and specific role which include prediction or forecasting the future, explore the future or scenario analysis, and back casting which can be achieved by general purpose models. The specific function models include demand models, energy supply models, impact models, appraisal models. Recent models generally have an integrated approach and combine several specific purposes in their approach. Demand-supply matching models and impact-appraisal models are common examples of integrated models, but an integrated approach is also required to study energy economy-environmental interactions. Also, almost all models include some indication of costs as a means for appraisal. Some models are constructed as a modular package, which enables the user to select only those modules or sub models that are relevant for the problem being studied. Another aspect concerning the purpose is what form of energy the model addresses, although not all models incorporate all forms and some models just focus exclusively on electricity while others just address "energy" as a whole, without differentiating forms of energy [20].

3.1. The model structure: internal and external assumptions

Other than the role or purpose of the model, models can be classified or distinguished based on the structure particularly the assumptions on which models are based. In model development, decision should be made on which assumptions are embedded in the model i.e., internal assumptions and which one are determined by the user i.e., external or inputs. Hourcade *et al*. [24] identified 4 independent dimensions for characterization of models in terms of degree of endogenization, extent of description of non-energy sector components, extend of description of energy end uses and extend of description of energy technologies. Hourcade *et al*. [24] identified 4 independent dimensions for characterization of models in terms of degree of endogenization, extent of description of non-energy sector components, extend of description of energy end uses and extend of description of energy technologies. Endogenization is the degree to which a model incorporates all parameters in the model equation to minimize exogenous parameters.

Endogenous models are predictive while back casting models or exploratory models rely on external or input parameters and assumptions about a behavior making them more suitable for simulation of effects of change in patterns historically [20]. Non energy sector components of the economy include investment, trade, income distribution, trade, energy consumption of non-energy goods. Models that present more detailed description of non-energy sector components are more suitable for analysis of effect of energy policy on the economy [20]. Models having more detailed description of end application of energy are more suitable for application in analysis of technology potential for energy efficiency [20]. The fossil fuels substitution potential of various technologies is better analyzed by models that allow more detailed description of technologies. Models with economic background tend to present technology in aggregate terms making them unsuitable for analysis of different energy supply technologies. Model users are expected to make external assumptions about these parameters being analyzed. According [24], external assumptions often include assumptions about: population growth, economic growth, energy demand, energy supply, price and income elasticity of demand, and existing tax system and tax recycling.

3.2. The analytical approach: top-down vs. bottom-up

Bottom-up long-term (LT) energy-system planning models may have a stylized temporal representation and they don’t consider techno-economic operational constraints of power plants so as to limit computational cost. The simplifications have an impact on the results obtained. Increased level of temporal and techno-economic operational detail increases the cost of computation. The bottom-up, long-term (LT) energy system planning models are often used in analysis of pathways for the transition of energy system and to deduce policy advice. Commonly used models for bottom u long term energy system planning include MARKAL/TIMES, PRIMES, EnergyPLAN, IKARUS, and PERSEUS. Specific analysis include feasibility of realizing ambitious targets for renewable energy or the reduction of greenhouse gas (GHG) emissions, the role of specific technology or the role of specific policy measures on the energy transition pathway [25].

3.2.1. Partial equilibrium models

Partial equilibrium models assess one sector or a certain subset of sectors. These energy models focus on energy demand and supply and neglect some interrelations and effects on the wider economy. Partial equilibrium models can capture more technological details than conventional computable general equilibrium (CGE) models. Examples of partial equilibrium models are the prospective outlook on long-term energy system (POLES) model used and developed by Enerdata in collaboration with European Union and University of Grenoble-CNSR, the world energy model (WEM) of the International Energy Agency, and the PRIMES Energy System Model of the European Commission [22], [26].

3.2.2. Optimization models

These models are developed for optimum allocation of renewable energy resources with commercial and technical considerations. These models involve formulation of allocation models that facilitate allocation of various renewable energy sources like wind, solar and biomass which are widely available bur supply or availability may be variable and unpredictable [3]. Optimization models attempt to define the optimal set of technology options needed to realize a specific target at minimized costs within certain constraints leaving prices and quantity demanded fixed in its equilibrium. An example is the MARKAL model which is used to analyses energy demand and supply at country level by application of bottom-up, dynamic modelling approach. It is feasible to simulate the energy demand of the service and industrial sector due to their technological variety where cost information cannot be made available. Optimization models neglect market imperfections and obstacles in many final energy sectors and conversion sectors like co-generation are not simulated which leads to unrealistic projected energy demand [22]. The sensitivity analysis for optimization models can be done by altering energy potential, energy demand, reliability, related emissions and employment factors of energy resources [3].

3.2.3. Simulation models

Simulation models give a descriptive, quantitative illustration of energy demand and conversion based on exogenously established drivers and technical data whose objective is to model observed and expected decision-making that does not follow the minimum cost rule. The drivers are correlated with the general economic and demographic development as well as other boundary conditions like energy and climate change policies and regulations. Minimization models have traditionally been used for planning and operation of the electricity sector although these models are not well suited to the more recent developments brought about by restructuring electricity for many countries. Therefore, models that consider imperfect competition have been developed. Flexibility of simulation models allows integration of aspects like strategic behavior or the absence of complete information. Examples of simulation model include system dynamics (SD) and agent-based simulation models. Specific models include the residential end-use energy planning system (REEPS), world energy model (WEM), mesures d'utilisation rationnelle de l'energie (MURE), and the national energy modelling system–residential sector demand module (NEMS-RSDM) [22]. Other simulation approaches in applied in research oligopolistic electricity markets are models like Cournot, Bertrand, and supply function equilibria. The hybrid Bertrand-Cournot model is a recent model application for electricity sector analysis where Yao and Oren propose a simulation model of a simplified electricity sector with special emphasis on the transmission situation and prices and the analysis of market and power [27].

3.2.4. Multi-agent models

Multi-agent models capture some market imperfections like strategic behavior, asymmetric information, and other non-economic influences in the modelling. These models are derived from the distributed artificial intelligence concept like macro level complexities in the early 1990s. Expanded use of agent-based modelling has been enhanced by development in computational methods and resources and multi-disciplinary ecological and natural resource research methodologies as well as development in more specialized statistical approaches especially to decision and policymakers. Agent-based models are regarded models for end-users to improve decision-making and test specific policies and project alternative scenarios and futures [22]. Mullti-agent models are limited to applications of the energy converting technologies and a few applications on final energy sectors. The main challenge of developing and using multi-agent models is high demand on additional empirical data for simulation. The modern macroeconomic or top-down energy models have their origin in the 1950s as a response to rapid economic growth and corresponding rising energy demand. The top-down models attempt to depict the entire economy on regional or national level and determine the aggregated effects of energy related policy changes like climate change policies in monetary terms [23]. However, current top-down models tend to include demand forecasting and include technological and economic feedbacks and non-financial or non-price policies like technical standards, norms. An example of such a model is the global optimization model MERGE which combines a top-down approach to model economy and energy demand with a bottom-up approach to capture the energy sector [22], [28].

3.2.5. Input-output models

These models are used for a structural description of the regarded economy, and they describe total flow of goods and services of a country subdivided into different sectors and users in terms of value added and specific input/output coefficients. These models are more suitable for short-term evaluation of energy policies rather than long-term ones as they can only give a current picture of the underlying economic structure based on historical data [22].

3.2.6. Econometric models

Econometric analysis is a combination of economic theory, mathematical tools, and statistical methods. Early economic models aimed at testing economic application of empirical evidence. Over time, econometrics increased from pure hypothesis testing to the development of complex econometric models. Most econometric energy models are open-ended, growth-driven macro econometric models that use time series data for aggregation, e.g., output analysis without assumption of equilibrium. Cross section and panel data is often used in micro econometrics. Econometric data rely heavily on data and need huge data to give credible results (methods of estimation). An example of econometric model is E3ME which is an annual macro econometric model for simulation of the GDP with 41 branches for all EU Member countries. Factors considered in the model include employment, value addition, prices, energy, and environmental [22].

3.2.7. Computable general equilibrium models

The computable general equilibrium (CGE) models originated in the general equilibrium theory developed by Léon Walras in the 1870s, Vilfredo Pareto in 1906 and Kenneth Arrow and Gerard Debreu in the 1950s, but the current computable general equilibrium models use different approaches to analyze policy implications for economies. This includes the Keynesian models. These models assume that all markets are in perfect equilibrium as a start point. They use social accounting matrices (SAM) to represent their benchmark data in equilibrium. Then policy intervention like special taxes or subsidies are introduced to maintain the equilibrium. These models are used commonly for long term simulations like the GEM-E3 model of the

European Commission, the Global Trade Analysis Project (GTAP) model consortium, and World Bank models. By adopting the equilibrium approach, computable general equilibrium models avoid energy efficiency limitations, delayed adjustment and generally neglect market failures [22], [29].

3.2.8. System dynamics

System dynamics (SD) modelling concept was developed by Forrester in the 1950s at the Massachusetts Institute of Technology (MIT) for use in analysis of long-term behavior of social systems. These systems include large industrial companies and entire cities. The objective of the model is to explain the interaction behavior of social system because of an assumed interdependencies with regard of dynamic system changes over time. The models involve use of differential equations and analysis among the components of the system. The model involves definition of flows, stocks, and central components of the system. The interconnections defined by feedback loops represented by non-linear differential equations. Another important aspect of the system dynamics theory and methodology is the decision theory modelled complex social systems. Differential analysis with mathematical formulations is used to describe the development over time. Forrester and associates were able to develop software tools to use differential equations for computation of the dynamic equations of the feedback system and its progress or variation over time by incorporating expert opinions. If there are no analytical or data-based solutions the programmes can provide capabilities to use experimental modelling approaches [22], [30].

3.3. Mixed energy models

Hybrid models combine two or more modelling frameworks to capture different dimensions of energy systems. Such frameworks combine large macroeconomic models with long term energy models, long term energy systems with models with short term operation models or three types of models for complex modelling frameworks. Examples of models that combine different frameworks of modelling are the TIMES + EMPS framework from the Institute of Energy and Technology and PERSEUS + AEROLIUS framework from the French-German Institute of Environment Research of the University of Karlsruhe [4]. Hybrid energy models improve the analysis and accuracy by decision makers and planners by addressing the limitations of individual bottom up and top-down energy models and are widely use by governments, international organizations, and agencies like the United Nations Environment Programme (UNEP), International Energy Agency (IEA) and energy generation and utility companies and energy service and product providers [22].

4. MATHEMATICAL OPTIMIZATION

Mathematical optimization is used in modelling to deal with redundancy in system specifications to deliver least cost. Some of the techniques used are derived from operations research. They mostly rely on linear programming like including mixed-integer programming, but others make use of nonlinear programming. Solvers may use classical or genetic optimization, such as the covariance matrix adaptation evolution strategy (CMA-ES). Models may be recursive-dynamic, solving sequentially for each time interval, and thus evolving through time. Or they may be framed as a single forward-looking intertemporal problem, and thereby assume perfect foresight. Single-year engineering-based models usually attempt to minimize the short-run financial cost, while single-year market-based models use optimization to determine market clearing. Long-range models attempt to minimize both the short and long-run costs as a single intertemporal problem. Long-range models deal with annual intervals, on the basis of typical daily trends and making them unsuitable for variable renewable energy. For proper planning of upfront daily dispatch, optimization is used in the planning of systems with a significant portion of intermittent energy generation based on future energy predictions [20].

5. ENERGY MODEL IMPLEMENTATION LANGUAGES

There are various implementing languages for energy models. These languages include GAMS, MathProg, MATLAB, Mathematica, Python, Pyomo, R, Fortran, Java, C, C++, and Vensim while occasionally, spreadsheets are also used. Integrated models combine simplified sub-models of the world economy, agriculture and land-use, and the global climate system in addition to the world energy system. These models include GCAM, MESSAGE, and REMIND [20].

6. COMMON ENERGY/ELECTRICITY MODELS

Electricity sector models are used to model electricity systems at national or regional level depending on circumstances. Engineering-based models usually contain a good characterization of the technologies involved, including the high-voltage AC transmission grid where appropriate. Some models may assume a single common bus or "copper plate" where the grid is strong. The demand-side in electricity sector models is typically represented by a fixed load profile. Market-based models additionally represent the prevailing electricity market and may include nodal pricing. For the purpose of capturing and studying strategic behavior of markets, game theory and agent-based models are used [20]. There exist several energy models today that have different applications. These models are more often run by national governments. Some of these models include LEAP, MAPS, PROMO, PSSE, MARS, MARKAL, TIMES, and NEMS which are discussed below.

6.1. LEAP

LEAP stands for long range energy alternatives planning system and is a software tool for energy policy analysis and climate change mitigation assessment. LEAP was developed at the Stockholm Environment Institute's (SEI) US Center for application in examination of city, regional, state, and national, energy systems. It is ideally used for forecasting studies of between 20–50 years. In its computations, most calculations occur on annual intervals. The model enables policy analysts to generate and evaluate alternative energy scenarios and to compare their energy requirements, social costs, benefits, and environmental impacts of the alternative options [20].

6.2. MAPS

MAPS stands for multi-area production simulation and is a production simulation model used by regional power transmission organizations and independent system operators to plan for economic impact of proposed electric transmission and generation facilities in wholesale markets. Some portions MAPS may be used for commitment and dispatch phase and updated t an interval of 5 minutes in the operation of wholesale electric markets for RTO and ISO regions. ABB' developed PROMOD which is a similar software package. The ISO and RTO regions also utilize a GE software package called multi-area reliability simulation (MARS) for power system reliability criteria a loss-of-load-expectation (LOLE) of no greater than 0.1 days per year. Further, a GE software package called positive sequence load flow (PSLF) and a Siemens software package called power system simulation for engineering (PSSE) analyzes load flow on the power system for short-circuits and stability during preliminary planning studies by RTOs and ISOs [20].

6.3. MARKAL/TIMES

MARKAL stands for MARKet ALlocation and was developed by the energy technology systems analysis programme (ETSAP) of the (IEA). It took about two decades to develop these modelling too. It is an integrated energy systems modeling platform, for analysis of energy, economic, and environmental issues at the global, national, and municipal level over timeframes of up to several decades. This model can be used to establish the impacts of policy options on technology development and natural resource depletion. TIMES which stands for the integrated MARKAL-EFOM system is an evolution of MARKAL, but the two models have a lot of similarities. TIMES succeeded MARKAL in 2008. Both models are technology explicit, dynamic partial equilibrium models of energy markets. In both cases, the equilibrium is determined by maximizing the total consumer and producer surplus via linear programming. TIMES and MARKAL are popular models used which in 2015, were used in 177 institutions spread over 70 countries [20].

6.4. National energy modeling system (NEMS)

NEMS is run by the Department of energy (DOE) and is used to compute equilibrium fuel prices and quantities for the US energy sector by iteratively solving a sequence of linear programs and nonlinear equations. NEMS is used explicitly as demand side model specially to determine consumer technology choices in the residential and commercial building sectors [20].

6.5. MERGE

MERGE is a top-down energy model used in energy planning [31]. The model MERGE creates a framework for thinking and planning climate change mitigation measures and proposals. The model allows one sufficient flexibility to explore alternative views on a wide range of issues like costs, valuation, damages, and discounting. There is high degree of uncertainty surrounding the climate change debate. Therefore, it is unrealistic to have consensus in cost-benefit analysis to on a bottom line. Based on this, the model MERGE is viewed as a research tool that can give insights into various aspects of the climate debate. This helps to focus the debate and identify the areas for further research that can yield higher pay-off [22], [28]. In MERGE, we focus on three of the most important anthropogenic greenhouse gases: carbon dioxide (CO), methane (CH), and nitrous oxide (NxO) are the three very important anthropogenic gases focused on the model MERGE. Important relationship for analysis is the emissions and atmospheric concentrations as well as the impact on temperature. To merge, other emissions from other sources are exogeneous inputs to MERGE [22], [28].

6.6. Greensmith energy management system (GEMS)

GEMS is an intelligent energy management platform developed and owned by Green Smith Company currently owned by Watsilla. GEMS is an energy management software platform that monitors, controls, and optimizes energy generation. It can be used to control energy storage, renewable energy sources, and thermal generation assets at increments rates of 100 milliseconds, while utilizing machine learning, historic data, and real-time data analytics to calibrate the generation needed at a given time. Through GEMS, it is possible to design, integrate and manage power generation assets and resources. GEMS is deployed in more than 70 grid-scale systems in nine countries. The system is integrated with a multitude of thermal and renewable generation system, as well as load and weather forecasting data [32]. Therefore, GEMS can help increase revenue and return on investment ROI by maximizing battery performance and longevity. It can facilitate "energy arbitrage" which allows the e customer to purchase electricity from the market when prices are low and store own generation for sale when the prices are high.

6.7. MESSAGE

MESSAGE is another supply optimization model which was developed by the Austrian International Institute for Applied Systems Analysis (IIASA). Message hosts 11 regions and computes the evolution of the energy sector up to the year 2100. The dispatch and investment model for electricity (DIME) markets in Europe model is another model used for linear optimization model for medium- and long-term forecasting of for (13 Central and Western European countries including Switzerland), electric power generation market covering 11 electric power generation technologies. The model is applied to simulate allocation and investment decisions on supply side of the electricity sector [33], [34].

7. RESULTS AND DISCUSSION

The transition to renewable and low carbon energy sources has become a primary objective for all nations to achieve sustainable development [8], [18], [19]. Energy system modelling continue to face several challenges that are often originating from the process of mathematical modelling. Of significance to note is the complexity and uncertainty in energy modelling and models to both users and developers of energy models. Other challenges relate to interpretation and communication of model output and results which may not be tackled by the model or modelling framework used. Models on public policy been criticized for being opaque or insufficiently transparent to users. As a solution to this challenge, the source code and data sets developed and used should be made available for peer review, and if possible publication for wider access and acceptance. For greater model transparency and hence acceptance models are some models can be availed as open-source software projects, often developing a diverse community as they proceed for example OSeMOSYS is an example of open source model see Table 1 [20].

Table 1. Models and applications

No	Models	Model characteristics and applications
1	Modelling energy and grid services (MEGS)	Model addresses critical grid services such as reserve, inertia, and firm capacity and balance energy at each timestep.
2	NEMS	Used to compute equilibrium fuel prices and quantities for the US energy sector by iteratively solving a sequence of linear programs and nonlinear equations.
3	GEMS	Used monitor, controls, and optimizes energy generation. It can be used to control energy storage, renewable energy sources.
4	MARKAL/TIMES	Both models are technology explicit, dynamic partial equilibrium models of energy markets. In both cases, the equilibrium is determined by maximizing the total consumer and producer surplus via linear programming.
5	LEAP	LEAP is a software tool for energy policy analysis and climate change mitigation assessment.
6	EnergyPLAN	EnergyPLAN is used as energy system analysis tool applied in the study, research, and design of future sustainable energy options.
7	Model for analysis of energy demand (MAED)	Used to evaluate the future energy demand based on medium- to long-term scenarios of socioeconomic, demographical, and technological development.
8	Home energy management system (HEMS)	Integrates power generation, power consumption, and energy storage equipment in the home for control and management and realize two-way communication.
9	WASP	Used to establish optimal long-term expansion plans for electricity generation or power systems with system constraints being defined by the user.
10	MESSAGE	A modeling framework for medium- to long-term energy system planning, energy policy analysis, and scenario development, MESSAGE is used to construct energy chains.

8. CONCLUSION

Various energy models are available for application by different users globally. Top down and bottom-up energy models have been improving over time to more detailed structures, with more empirically based equations and increased multi-agent aspects as demand for more accurate and reliable models increases. Various factors can be used in energy planning and optimization by model developers and users. They include gross income for businesses or countries, gross profit, gross national product (GNP)/energy ratio, energy production/generation and population among others. In modeling important energy parameters and functions include, technology availability, energy efficiency, energy supply, energy demand, a country's employment levels, or growth and energy resource availability. Overall aggregate characteristics of energy supply and consumption can be reflected by behavioral or econometric models and macro-statistical single-entity models. For medium-term forecasting econometric models are best suited in all time frames and many conditions. In objective function formulation, efficiency, and cost factors, are critical parameters in energy modelling. Where the objective is to determine how energy-economy interactions work, and predict and plan the future, energy–economy models are quite useful. This study has shown that energy models can be used to promote discussion and formulation of necessary energy policies, appropriate to prevailing situations or circumstances. Energy models on utilization of renewable energy consider factors like the system lifespan, system reliability, level, or degree of intermittence in supply, dimensions in site selection, economic and investment factors, and social acceptance. Various tools and software for modeling and optimization of grid electricity but, GEMS, MEGS, WASP, HEMS showed promise for optimized real time as well as middle range grid connected energy system with a mix of renewable, variable energy sources and thermal electricity/energy sources. For use in middle as well as long range energy modeling, identified models include EnergyPLAN, MAED, MESSAGE, and LEAP. Therefore, model options are many based on application, data, time, approach, cost, access, and availability to users.

REFERENCES

[1] M. J. B. Kabeyi and O. A. Olanrewaju, "Development of a cereal grain drying system using internal combustion engine waste heat," in *Proceedings of the International Conference on Industrial Engineering and Operations Management*, 2021, pp. 952–965.
[2] M. J. B. Kabeyi and O. A. Olanrewaju, "Fuel from plastic wastes for sustainable energy transition," in *Proceedings of the International Conference on Industrial Engineering and Operations Management*, 2021, pp. 1023–1034.
[3] S. Jebaraj and S. Iniyan, "A review of energy models," *Renewable and Sustainable Energy Reviews*, vol. 10, no. 4, pp. 281–311, Aug. 2006, doi: 10.1016/j.rser.2004.09.004.
[4] A. Pina, C. A. Silva, and P. Ferrão, "High-resolution modeling framework for planning electricity systems with high penetration of renewables," *Applied Energy*, vol. 112, pp. 215–223, Dec. 2013, doi: 10.1016/j.apenergy.2013.05.074.
[5] M. J. B. Kabeyi and O. A. Olanrewaju, "Conversion of a flash power plant to organic rankine system for Olkaria geothermal power plants," in *2021 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME)*, Oct. 2021, pp. 1–8, doi: 10.1109/ICECCME52200.2021.9591048.
[6] M. J. B. Kabeyi and O. A. Olanrewaju, "Performance analysis and evaluation of Muhoroni 60MW gas turbine power plant," in *2021 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME)*, Oct. 2021, pp. 1–8, doi: 10.1109/ICECCME52200.2021.9591134.
[7] E. Rhodes, K. Craig, A. Hoyle, and M. McPherson, "How do energy-economy models compare? A survey of model developers and users in Canada," *Sustainability*, vol. 13, no. 11, May 2021, doi: 10.3390/su13115789.
[8] M. J. B. Kabeyi and O. A. Olanrewaju, "Managing sustainability in electricity generation," in *2020 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, Dec. 2020, pp. 530–536, doi: 10.1109/IEEM45057.2020.9309994.
[9] M. J. B. Kabeyi and O. A. Olanrewaju, "Central versus wellhead power plants in geothermal grid electricity generation," *Energy, Sustainability and Society*, vol. 11, no. 1, Dec. 2021, doi: 10.1186/s13705-021-00283-8.
[10] M. J. B. Kabeyi and O. A. Olanrewaju, "Relationship between electricity consumption and economic development," in *2021 International Conference on Electrical, Computer and Energy Technologies (ICECET)*, Dec. 2021, pp. 1–8, doi: 10.1109/ICECET52533.2021.9698413.
[11] IRENA, "Energy transition outlook," *International Renewable Energy Agency (IRENA)*. https://www.irena.org/energytransition (accessed Feb. 20, 2022).
[12] IRENA, "Smart electrification with renewables: driving the transformation of energy services," *International Renewable Energy Agency (IRENA)*, 2022.
[13] M. J. B. Kabeyi and O. A. Olanrewaju, "Sustainable energy transition for renewable and low carbon grid electricity generation and supply," *Frontiers in Energy Research*, vol. 9, Mar. 2022, doi: 10.3389/fenrg.2021.743114.
[14] M. J. B. Kabeyi and O. A. Olanrewaju, "Geothermal wellhead technology power plants in grid electricity generation: A review," *Energy Strategy Reviews*, vol. 39, Jan. 2022, doi: 10.1016/j.esr.2021.100735.
[15] C. S. Lai, G. Locatelli, A. Pimm, X. Wu, and L. L. Lai, "A review on long-term electrical power system modeling with energy storage," *Journal of Cleaner Production*, vol. 280, Jan. 2021, doi: 10.1016/j.jclepro.2020.124298.
[16] A. Rana and G. Gróf, "Assessment of the electricity system transition towards high share of renewable energy sources in South Asian Countries," *Energies*, vol. 15, no. 3, Feb. 2022, doi: 10.3390/en15031139.
[17] V. Aryanpur, M. S. Atabaki, M. Marzband, P. Siano, and K. Ghayoumi, "An overview of energy planning in Iran and transition pathways towards sustainable electricity supply sector," *Renewable and Sustainable Energy Reviews*, vol. 112, pp. 58–74, Sep. 2019, doi: 10.1016/j.rser.2019.05.047.
[18] M. J. B. Kabeyi, "Geothermal electricity generation, challenges, opportunities and recommendations," *International Journal of Advances in Scientific Research and Engineering*, vol. 5, no. 8, pp. 53–95, 2019, doi: 10.31695/IJASRE.2019.33408.

[19] M. J. B. Kabeyi, "Feasibility of wellhead technology power plants for electricity generation," *International Journal of Computer Engineering in Research Trends (IJCERT)*, vol. 7, no. 2, pp. 1–16, 2020.
[20] N. M. J. P. Van Beeck, "Classification of energy models," *Tilburg University & Eindhoven University of Technology*, vol. 777, 1999.
[21] IPCC, *Climate change 2014 mitigation of climate change*. New York, NY, USA: Cambridge University Press, 2014.
[22] A. Herbst, F. Toro, F. Reitze, and E. Jochem, "Introduction to energy systems modelling," *Swiss Journal of Economics and Statistics*, vol. 148, no. 2, pp. 111–135, Apr. 2012, doi: 10.1007/BF03399363.
[23] C. G. F. Bataille, "Design and application of a technologically explicit hybrid energy-economy policy model with micro and macro economic dynamics," Ph.D. dissertation, Simon Fraser University, Burnaby, Canada, 2005.
[24] J.-C. Hourcade, M. Jaccard, C. Bataille, and F. Ghersi, "Hybrid modeling: new answers to old challenges introduction to the special issue of 'The Energy Journal," *The Energy Journal*, vol. 27, pp. 1–11, 2006.
[25] K. Poncelet, E. Delarue, D. Six, J. Duerinck, and W. D'haeseleer, "Impact of the level of temporal and operational detail in energy-system planning models," *Applied Energy*, vol. 162, pp. 631–643, Jan. 2016, doi: 10.1016/j.apenergy.2015.10.100.
[26] "POLES: prospective outlook on long-term energy systems," *Enerdata*. https://www.enerdata.net/%0Asolutions/poles-model.html%0A (accessed Feb. 20, 2022).
[27] J. Yao, S. S. Oren, and B. F. Hobbs, "Hybrid bertrand-cournot models of electricity markets with multiple strategic subnetworks and common knowledge constraints," in *Restructured Electric Power Systems*, Hoboken, NJ, USA: Wiley, 2010.
[28] A. Manne, R. Mendelsohn, and R. Richels, "MERGE: A model for evaluating regional and global effects of GHG reduction policies," *Energy Policy*, vol. 23, no. 1, pp. 17–34, Jan. 1995, doi: 10.1016/0301-4215(95)90763-W.
[29] A. Bernard and M. Vielle, "GEMINI-E3, a general equilibrium model of international–national interactions between economy, energy and the environment," *Computational Management Science*, vol. 5, no. 3, pp. 173–206, May 2008, doi: 10.1007/s10287-007-0047-y.
[30] K. Michael and S. Wolfgang, "The potential of alternative fuel cars for achieving CO2 reduction targets in EU27," 2010. http://www.astra-model.eu/pubblication/Alternative_Fuel_Cars_Michael_Krail.pdf. (accessed Feb. 20, 2022).
[31] M. Grubb, J. Edmonds, P. ten Brink, and M. Morrison, "The costs of limiting fossil-fuel CO2 emissions: A survey and analysis," *Annual Review of Energy and the Environment*, vol. 18, no. 1, pp. 397–478, Nov. 1993, doi: 10.1146/annurev.eg.18.110193.002145.
[32] WÄRTSILÄ, "Greensmith energy delivers enhanced energy management software platform GEMS 6," *WÄRTSILÄ*, 2018. https://www.wartsila.com/media/news/03-12-2018-greensmith-energy-delivers-enhanced-energy-management-software-platform-gems-6-2628044. (accessed Feb. 20, 2022).
[33] European Commision, "EU reference scenario 2016: energy, transport and GHG emissions : trends to 2050," *European Commision*, 2016. https://ec.europa.eu/energy/sites/ener/files/documents/20160713 draft_publication_%0AREF2016_v13.pdf.%0A
[34] European Commision, "Modelling tools for EU analysis," *European Commision*. https://ec.europa.eu/%0Aclima/policies/strategies/analysis/models_en.%0A