Review and Assessment of the Techno-economic Tools for Power Systems with Renewable Energy Penetration in Kenya.

M Tsuma[1] and S Kibaara[2]

***Abstract*—**Kenya is on the path of developing domestic renewable energy resources to reduce the overdependence on imported petroleum products and reduce carbon emissions. Presently, Kenya has increased the renewable energy penetration into the existing power systems for the purposes of reducing the overreliance on thermal power generation which stands at 36% and growing. Environmental conditions affect renewable energy generation thereby making energy supply to be intermittent and uncertain. To understand the potential use of renewable energy technologies and the Levelized Cost of Electricity (LCOE), there exist several techno-economic tools that offer great insights of the renewable power generation world over. These tools and methods categorized into financial analysis, impacts analysis and system analysis tools combine the capital costs, operation and maintenance costs, fuel costs and the energy output which when computed provide the necessary metrics which are indicators of project viability. LCOE is an economic assessment of the cost of energy generating system and should include all the life cycle costs, usually determined at the point where the sum of all the discounted revenues equalizes with the sum of all the discounted cost. However, there are certain aspects that are not covered by LCOE which includes damage from air pollution, energy security, transmission and distribution costs and the environmental impacts. This paper will present a review of these techno-economic modeling tools, identify their gaps and propose modifications to the LCOE calculations that will provide a realistic cost of electricity in Kenya's hybrid energy system.

Keywords: Levelized cost of electricity, Environmental Impacts, Life cycle cost

I. INTRODUCTION

As the global population and living standards increase, so is the increase in energy demand. Kenya through its Vision 2030 and the Big 4 Agenda envisions an improvement of living standards to her population which will demand an increase in electricity production to sustain the improved living standards and in turn reduce carbon dioxide gas emissions by 30% in 2030[1][2]. Kenya is rapidly developing its RES to reduce its over reliance on fossil fuels. For example, the geothermal energy has contributed immensely to overall electricity capacity, moving from 13% in 2011 to 26% in 2015 while Hydropower and fossil fuel based power add 36% each to the energy system [1]. Wind energy, cogeneration and solar PV contribute the remaining 2% with an annual growth of approximately 2.25%[3][1]. This increase in energy demand is to be met sustainably, that is without compromising the ecosystems and also be capable of meeting the energy needs for future generations. The immediate and future challenge has been and will always be meeting the energy needs of the ever-growing populations at the least cost possible, without affecting the environment and human health. To assess the viability of the energy resources before the power plant is constructed, techno economic assessment tools are used to estimate the performance of the plant, the likely pollutants that the plant will emit, the overall cost of the power plant and the ultimately the unit cost of power to determine the feasibility of the plant. Techno-economic tools selection subject to the objectives that one wants to achieve in an energy system[4]. The objective of this study is to assess and identify a tool among the many techno-economic assessment tools that is capable of incorporating the impacts of environmental effects in the calculation of LCOE. In the following section LCOE is discussed.

II. LEVELIZED COST OF ELECTRICITY

Many of the techno-economic tools use the levelized cost of energy LCOE as a comparative metric for assessing different energy power plants in relation to their lifetimes, cost structures, and capacity factors from an economical perspective[5]. LCOE is used by power producers as a utility factor to estimate the cost of power produced by any

[1]M Tsuma, Department of Electrical and Electronic Engineering, TUM (phone: +2540721545497:e-mail: mctsuma@gmail.com).
S Kibaara,Department of Electrical and Electronic Engineering, TUM(phone:+2540720443813:e-mail: kariukisamuel2004@gmail.com).

power plant[6]. The calculations to arrive at this factor takes into consideration all the expected lifetime costs of the power plant that includes all taxes, cost of fuel, capital expenditure for the project, incentives in form of grants, inflation rate,Operations and Maintenance costs and insurances, divided by the discounted energy production from the power plant[6]. The LCOE of power generation plants can be high or low. A low LCOE indicates a low unit cost of energy while a high LCOE indicates a higher unit cost of energy. Levelized Cost of Energy Cost (LCOE) is one of the famous indicators that can be used for economic analysis of an energy system. LCOE is calculated as shown by Equation 1 below[7]:

$$\frac{LCOE = TPV * CRF}{LAE} \quad \text{Eqn (1)}$$

Where $TPV$the total present cost of the entire system is, LAE is the annual load demand and CRF is the capital recovery factor.
CRF and TPV can be determined by[7][8] as shown by Equation 2 and 3 below:

$$CRF = \frac{r(1+r)^T}{(1+r)^T - 1} \quad \text{Eqn(2)}$$

$$TPV = IC + OMC + RC + FC - PSV \quad \text{Eqn (3)}$$

r is the net interest rate and T is the system lifetime in years, normally assumed to be 25 years.
is the initial capital cost of the power system (supply, installation/construction, testing and commissioning). OMC is the present value of operation and Maintenance cost of the Energy system over its lifetime (salaries, insurances, inspections, all maintenance activities, etc). OMC can be assumed to be a fixed cost per capacity of each component of the energy system [7]. The total OMC cost can be determined using the following equations 4 and 5[7]:

$$OMC = OMC_o \frac{(1+i)}{(r-i)} (1 - \frac{(1+i)^T}{(1+r)} \qquad for\, r \neq i$$

Eqn (4)

Or $OMC = OMC_o \, x \, T \quad for\, r = i$ Eqn (5)

Where $OMC_o$is the operation and maintenance cost a the first year of the project

RC is the present value of replacement cost of components in the energy system that will be carried out throughout the lifetime of the energy system and is calculated as indicated in Equation 6[7]:

$$RC = \sum_{j=1}^{N_{rep}} C_{RC} \, x \, C_U \frac{(1+i)^{T*j/(Nrep+1)}}{(1+r)} \text{Eqn 6}$$

Where i is the inflation rate of the replacement units which is around 5.7% in Kenya (Central Bank of Kenya). C_{RC} is the capacity of the replacement units, which is in kW for the energy system, C_U is the cost of the replacement units in Ksh/kW; N_{rep} is the number of replacement unit over the lifetime, T of the power system components. PSV is the present value of scrap. Calculation of PSV can be finalized as shown in Equation 7:

$$PSV = \sum_{j=1}^{N_{rep}} SV \quad \frac{(1+i)^{T*j/(Nrep+1)}}{(1+r)} \text{Eqn (7)}$$

III. TRADITIONAL SOFTWARE TOOLS AND ENERGY MODELLING TOOLS

There exist quite a number of software tools that can be used to optimize and simulate energy systems[4] Amongst these tools employed for techno-economic analysis are the Hybrid Optimization for Modeling Electrical Renewables (HOMER) , RETScreen Expert, SAM, Aeolius, EnergyPLAN, EnergyPro, MARKAL/Times, ETEM, Modest, Sifre, LEAP, BCHP Screening Tool, HYDROGEMS, and TRNSYS16 and many more[9][4]. HOMER and RETScreen are the most popular Techno-Economic tools. HOMER has the capacity of simulating and optimizing renewable power systems in standalone or grid linked configurations for the purposes of determining the cost effectiveness of the power plant[9]. This tool can be used to evaluate stand-alone power generation systems as well as grid connected systems in remote areas, islands and buildings to summarize their environmental, technical and economic benefits with a main objective of minimizing Net Present Costs (NPC)[9][4]. HOMER optimizes the system components of the power system to provide energy cost but does not look at all the costs associated with civil and structural work, installation and operation[4]. RETScreen is a project analysis and decision support tool which does not provide RE optimization but only analyses the energy scenario provided that the energy mix input is provided by the user[4]. This tool provides detailed cost analysis, financial analysis and emission analysis[4].

Salehin *et al.*, 2016 noted that HOMER omits costs like feasibility costs, development costs, civil engineering costs, system installation costs and

operational cost thereby making the levelized cost of electricity to be less than the actual cost of energy. They further noted that Energy Pro can be used to carry out a combined techno-economic design for fossil based and biofuel based power generation[4]. It is to be noted that though the common approach in modeling energy systems is through the use of one techno economic tool, several modeling frameworks exist that use two or more tools have been used to complement each other for the purposes of capturing key parameters of the energy systems.
Techno-economic analysis of power generation systems gives great insights into the economic viability of the power system to be designed and constructed.

IV. MODEL REVIEW OF TECHNO-ECONOMIC TOOLS

Due to the great importance of these tools in modeling, simulation and techno-economic analysis, there has been a number of studies that have attempted to assess the capability of these tools for the primary purpose of helping modelers identify the best tools for energy applications[10]. The reviewers have evaluated the features of the techno-economic tools highlighting the unique features that the tool has to meet specific objectives in techno-economic study of power generation systems [9]. Connolly *et al.*, 2010 has reviewed 68 techno-economic tools based on their capabilities to simulate, create scenarios, create equilibriums, carry out top-down and bottom up analysis, optimize operations and energy investments. They further analyzed and described in detail, in collaboration with developers 37 of these tools for the renewable energy penetration into the grid. They noted that BCHP Screening Tool, HOMER, HYDROGEMS, and TRNSYS16 have their primarily focus on stand-alone energy systems while EnergyPro undertakes feasibility studies of power plants, WASP analyses capacities of new power plants, ProdRisk and EMPS are used for optimization of hydro-power plants while the AEOLIUS is highly beneficial in analyzing the intermittency and uncertainty effects of RE penetration in conventional power systems. They additionally noted that ORCED simulates the dispatch of electricity, and EMCAS simulates electricity markets while BALMOREL, GTMax, RAMSES, and SIVAEL are applicable mostly in district heating and in electricity generation. The study revealed that E4cast, EMINENT, and RETScreen have the capability of addressing all aspects of heat and electricity sector for the primary purpose of improving the penetration of intermittent RE by using CHP and thermal storage. In addition to the heat sector, PERSEUS, STREAM, and WILMAR Planning Tool also included the transport sector in the form of electric vehicles and MiniCAM and UniSyD3.0 analyse hydrogen and electric vehicles into the transport sector. The reviewers noted that Invert, H2RES, and SimREN tools are applicable in the modeling of the use of biofuels and hydrogen vehicles respectively while COMPOSE, EnergyPLAN, ENPEP-BALANCE, IKARUS, INFORSE, LEAP, MARKAL/TIMES, MesapPlaNet, MESSAGE, NEMS, and PRIMES can account for all technologies in the electricity, heat, and transport sectors. However, they stated that only four of these, EnergyPLAN, MesapPlaNet, INFORSE, and LEAP have previously simulated 100% renewable energy-systems.
In conclusion, they noted that though there is a wide range of these tools in use, they differ significantly in terms of the regions they analyse, the technologies they consider, and the objectives they fulfil and[10] there is no single computer tool that can meet all the requirements in an energy system but each tool is only able to meet a specific objectives for a specific energy scenario. Additionally, the economic capabilities of these tools as analyzed are limited since no single tool has the capabilities of incorporating environmental impacts to LCOE costing.
Ringkjøb *et al.*, 2018 has reviewed, with the help of developers 75 computer-based techno-economic modeling tools by looking at the capabilities of these tools in terms of their general logic, spatiotemporal resolution as well as the technological and economic features for the purposes of aiding energy modelers identify the right tools for modeling. They assessed these tools based on their capabilities to analyse power systems, provide operation decision support, provide investment decision support, create scenario, to provide an engineering approach (top-down or bottom up approach), to create methodologies for energy and electricity models which deals with simulation, optimization, and equilibrium models. Additionally, the team analyzed the techno-economic tools based on their capability to model systems that have large percentage of variable renewable energy sources and also based on their capability to determine the technological and economic properties of grids and energy storage systems. Ringkjøb *et al.*, 2018 noted that the current suite of modeling tools can address most but not all challenges in a power system. Challenges such as short-term variability, incorporating the effects of climate change in power systems with high levels of renewable energy penetration cannot be easily addressed by the current crop of modeling suites.

Jebaraj and Iniyan, 2006 reviewed and classified energy models into energy planning, supply-demand, forecasting, emission reduction, optimization and modeling techniques. They observed that that the energy–economy models help in understanding the way in which energy–economy interactions work in a power system thereby enabling the prediction of future costing of energy. It's also noted that there is no model that incorporates the impacts to the environment of power systems in LCOE costing thereby making the LCOE to be lower than required.
Yue *et al.*, 2018 indicated that although energy system optimization models (ESOMs) have provided direction on how to handle energy policies and effects to the climate, the uncertainties within the model structures and the inputs these models have are not adequately addresses or ignored altogether. They compared other energy models to ESOMs and indicated that ESMs use scenarios to handle uncertainties or treat them as an elementary issue though they found out that model insights may be limited, lack robustness, and may mislead decision makers. They therefore provided an in-depth review of systematic in-depth review of the techniques that address uncertainties for ESOMs. We have identified four prevailing uncertainty approaches that have been applied to ESOM type models: Monte Carlo analysis, stochastic programming, robust optimization, and modelling to generate alternatives. For each method, we review the principles, techniques, and how they are utilized to improve the robustness of the model results to provide extra policy insights. In the end, we provide a critical appraisal on the use of these methods while Sinha and Chandel, 2015 focused their reviews on the optimization techniques of standalone hybrid renewable energy systems by reviewing of sixteen types of optimization techniques.
Lopion *et al.*, 2018 looked at the customization of climate goals into techno economic models to be in line with Paris Agreement. In their reviews, they looked at the trends, challenges and future requirements in energy system models based on their methodology, analytical approach, time horizon and transformation path analysis, spatial and temporal resolution, licensing and modeling language for the purposes of aiding researchers and decision makers find appropriate energy system models.

Further studies on the capabilities of standalone tools like EFOM, MARKAL, MOREHyS (Based on BALMOREL tool), Invert and UREM were discussed by Cormio *et al.*, 2003, Reza *et al.*, 2009, Almansoori and Betancourt-torcat, 2016/Robu and Bikova, 2010, Cai et al., 2009 respectively. These studies looked at the strengths individual tools without looking at the weaknesses of these tools.

V. CONCLUSIONS AND RECOMMENDATIONS

Arising from the reviews, it can be concluded that Energy modeling suites are designed with different end uses, research problems in mind and they are diverse in terms of their structure, operation, and applications. Though the objectives of these tools vary, they are all used in one way or the other in the energy sector to model, simulate and optimize power systems to accommodate the fluctuations of renewable energy, or to provide a long-term report for 100% renewable energy system. It has also been noted from the reviews that there is no tool that integrates the impacts of environmental effects in LCOE costing. R& D should be geared towards re-modeling the LCOE to incorporate the impacts of environmental effects for the purposes of upgrading an energy modeling, simulation and optimization suite with enhanced LCOE calculations.

References

[1] F. Dalla and B. Van Der Zwaan, "Do Kenya ' s climate change mitigation ambitions necessitate large- scale renewable energy deployment and dedicated low-carbon energy policy ?," *Renew. Energy*, vol. 113, pp. 1559–1568, 2017.

[2] S. Abdullah and P. W. Jeanty, "Willingness to pay for renewable energy : Evidence from a contingent valuation survey in Kenya," *Renew. Sustain. Energy Rev.*, vol. 15, no. 6, pp. 2974–2983, 2011.

[3] E. Roadmap, "RENEWABLE," 2016.

[4] S. Salehin, M. T. Ferdaous, R. M. Chowdhury, S. Shahid, M. S. R. B. Ro, and M. Asif, "Assessment of renewable energy systems combining techno-economic optimization with energy scenario analysis," vol. 112, 2016.

[5] H. Lotfi and A. Khodaei, "Levelized cost of energy calculations for microgrids," *IEEE Power Energy Soc. Gen. Meet.*, vol. 2016–Novem, pp. 1–5, 2016.

[6] S. S. Chundawat and K. V. S. Rao, "Levelized electricity cost of two grid connected biomass power plants," *2016 - Bienn. Int. Conf. Power Energy Syst. Towar. Sustain. Energy, PESTSE 2016*, pp. 1–6, 2016.

[7] M. Abdelaziz Mohamed and A. M. Eltamaly, *Modeling and Simulation of Smart Grid Integrated with Hybrid Renewable Energy Systems*, vol. 121. 2018.

[8] M. Melamed and A. P. A. Ben-tal, *Optimization of Energy Systems under Uncertainty*. .

[9] W. Ma, X. Xue, and G. Liu, "Techno-economic evaluation for hybrid renewable energy system : Application and merits," *Energy*, vol. 159, pp. 385–409, 2018.

[10] D. Connolly, H. Lund, B. V Mathiesen, and M. Leahy, "A review of computer tools for analysing the integration of renewable energy into various energy systems," *Appl. Energy*, vol. 87, no. 4, pp. 1059–1082, 2010.

[11] H. Ringkjøb, P. M. Haugan, I. M. Solbrekke, E. T. H. Zürich, and S. Pfenninger, "A review of modelling tools for energy and electricity systems with large shares of variable renewables," *Renew. Sustain. Energy Rev.*, vol. 96, no. July, pp. 440–459, 2018.

[12] S. Jebaraj and S. Iniyan, "A review of energy models," vol. 10, pp. 281–311, 2006.

[13] X. Yue, S. Pye, J. Decarolis, F. G. N. Li, F. Rogan, and B. Ó. Gallachóir, "A review of approaches to uncertainty assessment in energy system optimization models," *Energy Strateg. Rev.*, vol. 21, no. July 2017, pp. 204–217, 2018.

[14] S. Sinha and S. S. Chandel, "Review of recent trends in optimization techniques for solar photovoltaic – wind based hybrid energy systems," *Renew. Sustain. Energy Rev.*, vol. 50, pp. 755–769, 2015.

[15] P. Lopion, P. Markewitz, M. Robinius, and D. Stolten, "A review of current challenges and trends in energy systems modeling," *Renew. Sustain. Energy Rev.*, vol. 96, no. July, pp. 156–166, 2018.

[16] C. Cormio, M. Dicorato, A. Minoia, M. Trovato, P. Bari, and V. E. Orabona, "A regional energy planning methodology including renewable energy sources and environmental constraints," vol. 7, pp. 99–130, 2003.

[17] M. Reza, F. Zonooz, Z. M. Nopiah, and K. Sopian, "A Review of MARKAL Energy Modeling," vol. 26, no. 3, pp. 352–361, 2009.

[18] A. S. Almansoori and A. Betancourt-torcat, "Design of optimization model for a hydrogen supply chain under emission Design of optimization model for a hydrogen supply chain under emission constraints-A case study of Germany," no. July 2018, 2016.

[19] S. Robu and E. Bikova, "MARKAL Application for Analysis of Energy Efficiency in Economic Activities of the Republic of Moldova and Feasible use of Renewable Energy Sources," vol. 2, no. 13, pp. 90–103, 2010.