Modelling and optimization techniques of off-grid applications in developing countries

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DOI: https://doi.org/10.17102/bjrd.rub.10.2.017

Abstract

Worldwide, nearly more than half a billion people will still not have a reliable and affordable electricity till 2040 and nearly 1.8 billion may compel to rely on traditional fuel sources for day to day activities. Specially the case is even more critical in remote areas of developing countries. Energy planning models (EPMs), approaches and optimization techniques play an important role in energy sectoral policy formulation. Long term energy planning through energy modelling and optimization techniques of energy technologies have a better impact to mitigate the issue of energy access. Varieties of energy planning approaches, energy modelling and planning tools and techniques are available at global context. Energy demand forecasting and the subsequent planning is one of the most important aspect when dealing with long-term energy planning. The study has focused on energy trend of Nepal, energy planning methodologies, analysis of prevailing energy modelling and optimization techniques in context of developing and under developed countries.

Keywords: *Energy planning, Optimization tools, Energy access*

Introduction

A common meaning of energy planning is to develop or process long-range policies to addressfuture energy demand (Yazdanie, Densing, & Wokaun, 2018). In most of the developing countries like Nepal, energy is being fed from traditional sources e.g. biomass, fuel wood, animal dung (“Energy Sector Synopsis Report,” 2010). Countries where population density isvery low and geographical diversity is very high, energy planning is must(CBS, 2012). Electrification without better energy modelling, planning and optimization techniques would lead to high energy cost combined with snail pace of electrification(S. Bhattacharyya, 2013; Shrimali & Kniefel, 2011). Sluggish electrification will have ultimately negative impact on national gross domestic product (GDP). Thus, energy planning backed up with modelling and optimization is a pre-requisite to address the increasing energy demands. Because, better energy planning is achieved only by modelling all the available energy systems (Maheshwari,2013; Urban, Benders, & Moll, 2007).

Energy supply from isolated energy system or grid extension for developing countries with lowpopulation density is always a challenge. Thus, hybrid energy system has always been proven to be a better solution. But, increased complexity in comparison with single energy systems, the optimum design of a hybrid system becomes complicated (Kobayakawa & Kandpal, 2014) (Srinivas & Reddy, 2014). Optimum configuration and optimum control strategy of a system are closely interdependent. This complexity makes the hybrid systems more difficult to be designed and analyzed in comparison to the isolated ones. In order to efficiently and economically utilize the energy resources, optimum sizing method which can help to guarantee the lowest investment with full utilization of the resources is must. This type of optimization includes economic objectives and requires the assessment of the system's long-term performance in order to reach the best compromise for both reliability and cost(Hall & Buckley,2016; Y. Huang, Bor, & Peng, 2011; Jebaraj & Iniyan, 2006; Wagh & Kulkarni, 2018; Watchueng, Jacob, & Frandji, 2010). This issue can be further mitigated by following energy planning models and optimization techniques.

Rapid depletion of fossil fuel combined with rapid urbanization has raised an issue of energy access. Better energy access (i.e. above or equal to Tier 3) can be ensured with integrated energy planning for specific area is necessary for better energy planning("Energy Sector Synopsis Report," 2010) (De La Rue Du Can, Pudleiner, & Pielli, 2018; Iea, 2002). Haphazard electrification could duplicate the energy resources with less meaningful impact at end-users' level. During the energy modelling certain parameters need optimization to achieve better and long-range energy planning (Al-Sharafi, Sahin, Ayar, & Yilbas, 2017) (Sanjel & Baral, 2019;Sanjel, Baral, Acharya, & Gautam, 2019). Thus, energy modelling has been a standard tool for energy planning; short-term or long-term.

As of now various reviewers incorporates numerous energy modelling techniques, parametric optimizations and several energy planning approaches have been published in isolation(Ahmed& Khalid, 2019; Bhandari, Lee, Lee, Cho, & Ahn, 2015; S. C. Bhattacharyya & Timilsina, 2010; Herbst, Toro, Reitze, & Jochem, 2012; Parajuli, Østergaard, Dalgaard, & Pokharel, 2014; Philosophy, 1991). Such reviews lack comprehensive coverage of energy planning approaches, energy planning models, energy demand and supply models and energy forecasting models atan integrated level. Thus, the objective of this article is to analyze all the possible planning approaches and the models in a comprehensive way.

Electricity scenario in Nepal

Fig. 1 shows annual electricity generated from Nepal Electricty Authority (NEA), purchased from Indivdual power producers (IPPs), imported from India and the annual peak demand for the period of 2009 to 2019. The Fig. 1 shows almost linear electricity generation of NEA (including IPPs) against the steep gradient of peak power demand has ultimately increased thepower purchase from India. Until now, NEA has been importing electricity from India to meetthe gap. To meet the gap, power purchase is ever increasing as reflected in Fig. 1, which is most extensive in year 2018. The electricity demand may be full-filled by grid extension in case of densely populated areas and by stand-alone systems for sparsely populated areas.

For the trend analysis, electricity generated, purchase from India and the peak demand has beenregressed over the 10 years of time frame. The trend as depicted in Fig. 1 shows that, electricitygeneration slope is almost stagnant (slope = 40.1). Despite the stagnant slope (which has beenslightly increased than year 2018), peak demand has been lineraly increasing at a slope of 67.6.This gap in generation and demand has been managed by power purchase. Power purchase has been done from IPPs in Nepal and import from India. The integreated slope of purchase/importis moving towards ever increasing trend with slope of 384.2. The slope can be slightly normalized if the power purchase from IPPs and import from India are analyzed in isolation.

In contrary, the peak demand of year 2018 has been dropped abruptly. The reason behind thisabrupt down-fall is yet to be assessed and is recommend for the further research.

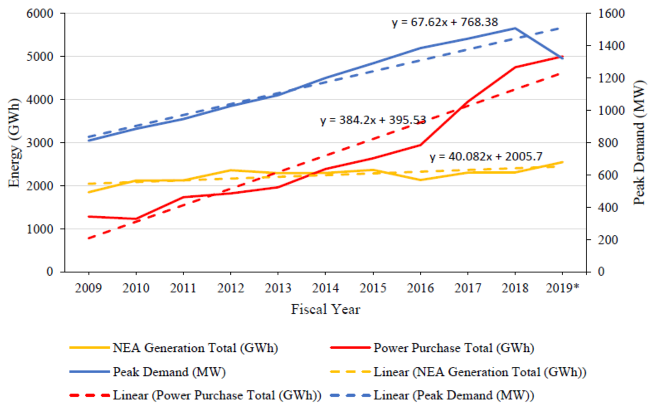

Fig. 1 Electricity generation, peak demand and integrated power purchase (Nepal Electricity Authority, 2018)

Energy planning methodology

The study has conducted in-depth study of energy planning methodologies proposed by numerous researchers and reviews(Haddad, Liazid, & Ferreira, 2017; IEA/OECD, 2012; Kalappan & Ponnusamy, 2013; Salisu & Ayinde, 2016). After analyzing those methodology, the researchers have proposed its own simple methodology or steps as stated below.

Step 1: Identification of load (demand analysis)

In this step, depending upon the scope of energy planning, demand load is identified for residential, commercial and industrial level. The data is collected from each user entity level. In case of sampling data collection, it is extrapolated to forecast the total current and future load demand.

***Step 2*: Assessment of meteorological conditions (resource analysis)**

Before planning to actual energy supply to meet the load demand, resource analysis isconducted. During the resource analysis, various meteorological conditions of hydropower, solar irradiation, wind velocity and biomass potential are assessed. Hydropower potential, current grid situation, solar irradiation, wind velocity, biomass potential etc are assessed in detail.

***Step 3*: Energy supply model (model analysis)**

Based on the resources available in the area, energy modelling is conducted. The modelling may be conducted in any of the appropriate tool, software or methodology. During the process of model identification, various models are tried and tested. The objective of the energy supplymodelling is to identify the best method/tool to electricity the area at least cost.

***Step 4*: Model development (optimized model)**

Once the model analysis is done, a best fit model is selected for energy planning. During the model development, various parameters under planning are optimized and tested for itsefficacy.

***Step 5*: Sizing using simulation and optimization (system configuration)**

Once the optimized model is finalized, exact energy planning is only possible based on forecasted load demand and the necessary system configuration of energy resources. Optimization also takes cares of the available technologies and resources for energy planning.

***Step 6*: Model implementation (contextualized system**

configuration)

After ensuring system optimization parameters, technology selection with configuration for the appropriate model, the model is implemented for the specific location.

One way or the other the above-mentioned steps are found relevant and being implemented by energy planners and proposed herewith.

Energy planning approaches

Based on various published articles and literature, the study here presents four best approaches for energy planning.

i. Bottom-up approach for energy planning

In this energy planning approach, energy demand of each household at specific time of day is recorded at primary level. The demand data for every household, commercial entity and industry is collected for better demand forecast. Further, the daily data is extrapolated (or recorded manually) to year-round data. In case, data collection of every entity is not possible, sampling may be conducted in a scientific way. The approach is very time consuming, but accuracy of the planning is very high.

ii. Top-down approach for energy planning

In top-down approach for energy planning, energy demand of each entity at user level is not collected. Basically, the energy demand data is considered from secondary source and extrapolated for demand forecast. Energy planning is done based on earlier data adding a factor for increase in energy demand; demand forecasting. The approach is very useful when a planning is to be carried out in short span of time and having no primary data at hand. But, the accuracy of the planning is relatively low than the bottom up approach.

iii. As usual approach for energy planning

The approach is not about top-down or bottom-up, but this is about giving continuity to the current energy planning method. Future load demand is forecasting by extrapolating the available demand data. This approach of energy planning is the least efficient approach for energy planning thus not recommended for execution.

iv. Hybrid approach for energy planning

Hybrid approach for energy planning is the mix of bottom-up and top-down approach. In this approach depending upon necessity, primary data is collected, and secondary data is utilized. So, it is the mix of top-down and bottom-up approach. Accuracy of the approach is high and is most widely used for efficient energy planning.

Optimization models

During energy planning models, the planner needs to optimize various technical and financial parameters and forecast the future scenario accordingly. Thus, these energy planning and forecasting models fall under the umbrella of optimization models or techniques. Depending upon requirements of energy planners and field situation, various energy optimization models are presented below.

Table 1 Comparison of energy optimization models.

Optimization models	Scope of the models	References
Analytical	Follows both top-down and bottom-up approach Least cost calculation Economic distance limit comparison	(Sanjel et al., 2019)(Mahapatra & Dasappa, 2012)

Hybrid Optimization of Multiple Energy Resources (HOMER Energy)	Follows bottom-up approach Techno-economic optimization Parametric optimization Sensitivity analysis	(Bhuiyan, Deb, & Nasir, 2013; Cuellar Bolaños, Ortiz, & Bhandari, 2014; R. Huang, Low, Topcu, Chandy, & Clarke, 2011; Husain, S.M. ; Sharma, 2014; Shaahid & El-Amin, 2009; Shahzad et al., 2017)
Long-range Energy Alternatives Planning (LEAP)	Follows bottom-up approach Energy system analysis Energy policy analysis and climate change mitigation Scenario-based modeling tool Covers both conventional and renewable energy sources	(Emodi, Emodi, Murthy, & Emodi, 2017; Hall & Buckley, 2016; Y. Huang et al., 2011; Poudyal, Loskot, Nepal, Parajuli, & Khadka, 2019; Sapkota, Lu, Yang, & Wang, 2014; Wagh & Kulkarni, 2018)
Model for Analysis ofEnergy Demand (MAED)	Follows bottom up approach Energy demand forecasting model Systematic framework for	(Nakarmi, Mishra, & Banerjee, 2016)(Herbst et

	mapping trends and anticipating change in energy needs, Covers both conventional and renewable sources	al., 2012; IBN Government of Nepal, 2011)

MARKAL	Follows bottom up approach Numerical model used to carry out economic analysis of different energy systems Optimal technology mix	(Nakarmi et al., 2016; Sarica & Tyner, 2013)
MESSAGE	Framework for medium to long-term energy system planning, energy policy analysis, and scenario development Identification of socioeconomic and technological response Description of future uncertainties Development of robust technology strategies and related investment portfolios to meet a range of user-specified policy objectives	(Herbst et al., 2012)
Econometric	Statistical model Specifies statistical relationship between various economic quantities pertaining to a particular economic phenomenon	(Larsen & Nesbakken, 2004; Parajuli et al., 2014; Shrimali & Kniefel, 2011; Smith & Shively, 2018)
Wien Automatic System Planning Package (WASP)	Framework for power system planning Determines the optimal long-term expansion plan for a power generating system Optimal expansion is determined by minimizing discounted total costs	(Migoya et al., 2007; Onat & Ersoz, 2011; Yang, Rojas, & Montlaur, 2019)

Discussion

The section onwards makes detail discussion over the above analyzed headings in achronological order.

i. Discussion of electricity scenario in Nepal

The review has conducted detail analysis of current electricity scenario of Nepal as an example for developing countries. The research shows a huge gap between electricity generation and the demand; which is ever increasing. This gap is being addressed by maximizing the electricity purchase/import. This increasing gap in electricity generation and import is moving towards unsustainability. It has a direct impact on national GDP. So, national policies should be formulated in such a way that electricity will be generated in an increasing slope.

ii. Discussion of energy planning methodology

The article has minutely analyzed various energy planning methodology and proposed a general methodology for energy planners. The methodology comprises of five steps for energy planning from demand forecast to model development and the execution. The proposed methodology is expected to be helpful to energy planners in developing and under developed countries.

iii. Discussion of energy planning approaches

The study has examined various energy planning approaches considered and published. The article has traced specific nature and scope of each planning approach. The study suggested that any of the approach may be implemented for energy planning depending upon the data availability. The researchers suggest a bottom up approach for better energy planning.

iv. Discussion of optimization models

The review has conducted analysis of various pertinent optimization tools and models. The study reveals that many of the optimization models basically focus on demand forecasting and follows bottom up approach. Depending upon necessity of energy planners, specific model may be implemented. For the energy model comparison, we evaluated the models according tothe main characteristics of developing countries' energy systems, pertinent optimizationmodels and techniques and the prevailing economies of the country. As a result, the model comparison with main characteristics of developing countries has been tabulated in Table 1. Table 1 shows that only few of the main characteristics are addressed by the compared energy models. Various optimization models and tools are unique in nature.

Summary and conclusion

The results show that, electricity trend of Nepal is moving towards unsustainability which hasbeen witnessed from increasing slope of electricity purchase and import from India relative to electricity generation. Analysis of the optimization tools and techniques show that currently energy models seem to be based towards status of the energy systems and economic indicatorsof the developed countries. However, it is different for the developing countries. Therefore, energy modelling should be done in isolation than a common approach for all. At the current situation, it is very difficult, to find a universal model that fulfills all requirements that may adequately address the energy systems and economies of any developing countries. This is due to technical restrictions, data inconsistencies, limited purposes of the models and the complexity of the system. Thus, the research concludes that, it is not possible to recommend aspecific optimization tool as a universal-approach. An optimization tool may fit in one situationbut may not fit into another. This concludes that an optimization technique can only be opted after determining the specific models for energy planning. The study has discussed pros and cons of the four pertinent energy planning approaches and concludes on recommending the bottom up approach as the better alternative among others. The research has proposed a five- step energy planning methodology starting from demand analysis, resource analysis, model analysis, model optimization and execution of the model. The proposed methodology is expected to be very helpful to energy planners and policy makers in developing and under developed countries.

Acknowledgement

Authors would like to extend their sincere thanks to University Grants Commission (UGC) Nepal for financial support in the research (UGC PhD fellowship award No.: PhD-75/76-Engg-2).

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