Long-Term Renewable Energy Integration Planning in India: Challenges and Opportunities

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***Abstract*—Variability and uncertainty associated with large scale renewable energy (RE) integration (solar, and wind) affect both power system operation and planning. Consideration of short-term system variation is crucial for designing optimal system portfolio. Traditional long-term planning approaches in India often do not consider these issues and over estimate the ability of the system to assimilate variable RE. In this article a hybrid iterative approach has been outlined, bridging the gap between short-term and long-term RE integration planning.**

I. Introduction

Energy system planning is a strategy for policy-makers to formulate new energy policies and design different pathways to achieve those policy targets. Over the years various models and associated tools have evolved with varying philosophies suitable for different applications. These planning models aim to identify the least cost solutions to meet future energy needs and policy targets. They report suitable technological options for energy supply, transformation, and end use by imposing several user constraints like minimum carbon dioxide emission, maximum renewable, and minimum nuclear energy penetrations, etc.

Climate change and energy security issues have emerged as major driving factors in various recent energy system planning studies. Increasing attention is being paid to find strategies to reduce greenhouse gas emissions for future energy systems. This interest has motivated the policy makers to analyze the role of renewable energy sources like solar and wind in future electricity generation mix as they have the potential to provide emission free energy. However, characteristics of renewable sources are different from conventional resources regarding spatial and temporal variability, making their modelling and representation for long term planning a challenging task.

To support variability and uncertainty from RE sources like solar and wind additional flexibility is required to maintain a reliable and stable system operation. Due to inherent modelling limitation, traditional planning approaches often fail to address the short-term variability and underestimate system flexibility need for reliable operation. Significant methodological revision is therefore required in countries like India where large scale RE penetration targets have been set up [1]. Effect of inefficient planning has already being witnessed in forms of RE generation curtailment [1] in several states (e,g, Tamilnadu, Rajasthan, etc.) in India [2]. Therefore, maintaining coherence between short-term operation and long-term planning methods is becoming strongly relevant for energy system portfolio designing.

This article discusses different planning approaches adopted in India, their limitations, and possible methodological improvement. The next section highlights different system planning approaches in India and their limitation in terms of considering RE variability. Section three discusses different ways to improve current system planning practices, and finally, Section four summarizes and concludes.

II. RE Integration Planning Approaches in India: Status and Limitations

Approaches towards designing long-term energy system in India are diverse. Different kind of models/ tools have been applied by various planning agencies focusing on different objectives. Power utilities often use integrated resource optimization models for generation and network expansion planning [3]. Models used by national level planners range from top-down macro economic to bottom-up energy system models [4], [5]. Different account balancing tools are also used by the planners to visualize the long-term effect of various energy policies on national scale [6]. These planning activities highlight that renewable energy sources like solar and wind would play a crucial role in future generation mix to reduce dependency on fossil fuel for electricity generation.

Despite this assessment, approaches to address short-term uncertainties associated with renewable generators are aggregated in these planning exercises. Due to inherent modelling limitations, the models used either by utilities or system planners hardly consider short-term resource variation. These models focus on resource adequacy to satisfy demand ignoring the quality of the system components. The objective of these models is to identify chronological investment decision over a long-term horizon rather than optimizing power system operations such as generator scheduling or dispatch. Due to the limited temporal and spatial definitions adopted in these models, representation of operation related constraints (generating units, transmission lines) is often ignored or oversimplified. Analysis of flexibility options for penetration of renewable energy in future techno-economic scenarios is often out of the scope of these studies [7]. Therefore, system portfolio reported by these planning activities corresponding to future large scale RE expansion targets are often unrealistic and unreliable. As the variable RE sources would play a significant role in future generation portfolio in India, a major modification of the current planning strategies is required.

[1]RE curtailment referees to the voluntary or non-voluntary reduction of generation from RE generators due to the inflexibility of the system.

III. Methodological Improvement for RE Integration Planning

Next generation planning methods need to reflect the effect of short-term variability from RE sources. Different approaches can achieve this. The methodological improvement in this regard can be done within the energy system models (endogenous methods) or using separate models (exogenous approaches).

A. Endogenous Approaches

The endogenous approaches try to perform methodological improvement within the system model itself by adopting higher temporal and spatial resolution. As the energy system models do not consider actual time series of demand or RE generation forecast, temporal resolution can be enhanced by adopting a higher number of annual time slices [2] [8], [9]. Spatial resolution can be improved by considering a large number of model regions instead of single one with electricity trade between the regions [10], [11]. Some recent attempts have tried to incorporate the operational constraints of system components (e.g. generator, transmission lines, etc.) within the modelling paradigm [12], [13]. Though endogenous approaches have the benefits of maintaining a single model, they are often criticized for adding additional computational burden and design complexity to the model [14]. In these attempts, improving single methodological aspect often does not provide additional benefit, and the representation of operational constraints are also often stylized and does not represent actual operation [15], [16].

B. Exogenous Approaches

Exogenous approaches are also termed as hybrid methods as they often involve the use of multiple models or tools. These models perform a particular task and are linked together to achieve a common goal. Power system operational scale models (e.g. optimal power flow, unit commitment, production cost) are often linked with planning models in either uni or bi-directional data transfer [17], [18], [19]. Here the planning model optimizes investment decisions, and the operational model optimizes short-term system operation in hourly or sub-hourly resolution. Through mutual data transfer, this approach attempts to design a portfolio which is realistic, flexible and can support large scale RE penetration. The bi-directional linking framework allows operational level information from short-term models to be transferred back to the planning model for any revision in solution. Thus, using this approach, chronological optimization of system portfolio up to the target year of interest is possible considering operational scale RE variability. The major benefit of hybrid modelling framework is that it utilizes the strengths of individual models/ tools avoiding unnecessary computational burden to a single one. However, establishing a proper route of data transfer, selection of converging criteria can be challenging in this case.

C. Proposed Approach

System planning models often utilize single annual capacity factor of a technology per region to calculate yearly generation as well as capacity requirement. Thus, it ignores

[2]Breaking a year into a large number of parts

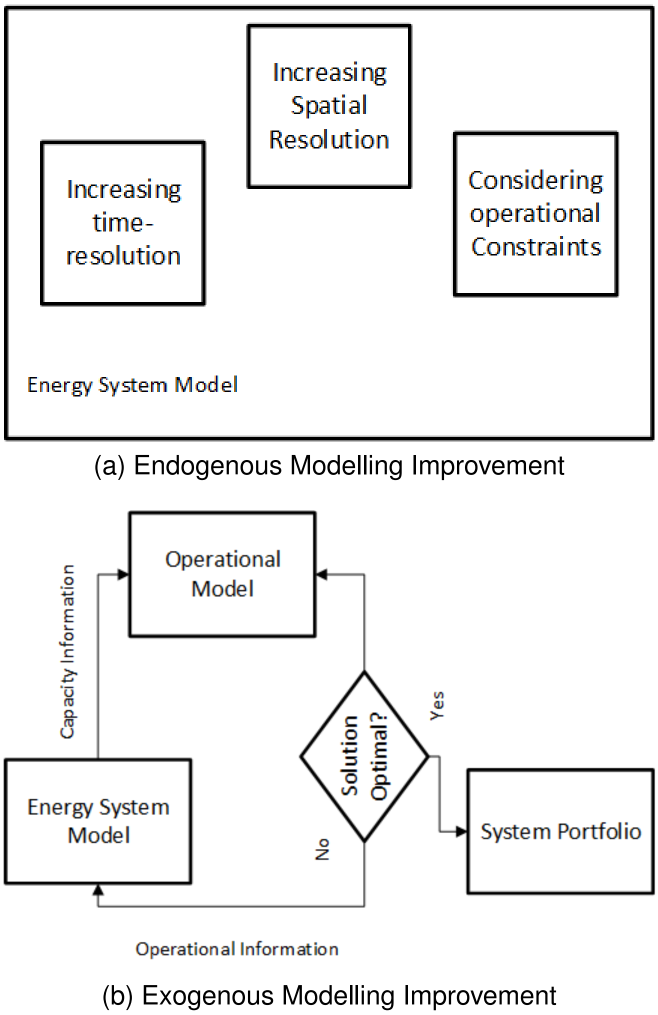


Fig. 1. Suitable and Excluded Areas for Solar PV Installation

the spatial as well as temporal variation of RE resource intensity. Such coarse representation of RE variability cannot complement the operational model used in hybrid modelling approaches. Here, an integrated modelling framework has been presented which tries to improve the representation of RE in the system model endogenously and utilizes a separate operational model via bi-directional linking to consider the effect of RE variability on system operation. As consideration of many regions is often prohibitive, each model region is divided into several geographical grid-cells. In figure 3 it has been shown that an energy system model with 'states' as regions can be further divided into 1-degree by 1-degree grid cells. Geographical information system (GIS) is used to derive high-resolution information related to annual capacity factor and the capacity potential for each grid cell considering resource intensity and land suitability. Historical hourly time series of wind speed and solar radiation of each grid cells are used to calculate average hourly capacity factor. These informations of each grid cells are then represented in the system model as a different technology with its own annual capacity factor, capacity bound, and time slice specific capacity factors. The system model is linked to an operational model similar to the exogenous approach to consider the effect of operational constraints on planning paradigm. Endogenous improvement of RE representation

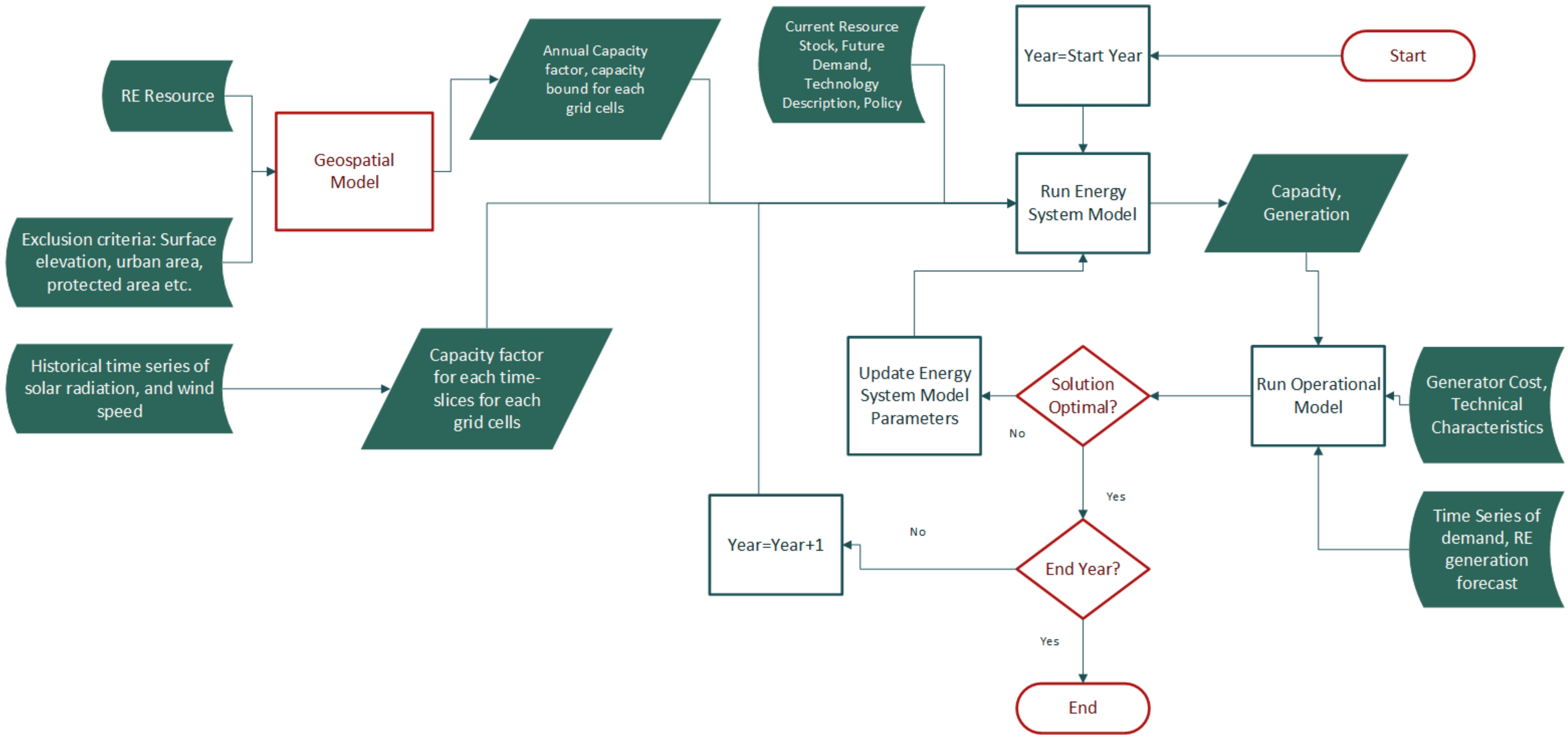
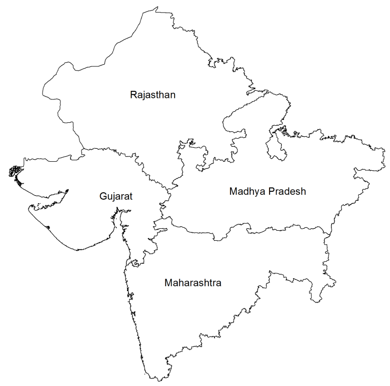
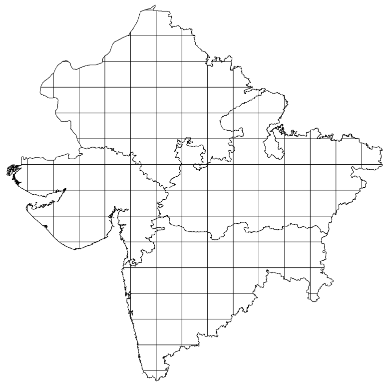


Fig. 2. Proposed modelling Approach



(a) Model Regions



(b) Model Regions Divided into Grid-Cells

Fig. 3. GIS based approach of dividing model region into grid-cells

within the system model and can better complement and utilize the benefit of the operational model in exogenous approach. The overall method has been illustrated in figure 2.

IV. Discussion and Conclusion

Changing the paradigm of current RE integration planning methods shall require increased coordination between different planning agencies and operational utilities. It will also require improved tools, algorithms, advanced data maintenance and management practices. Noting the challenges of system operation with a large share of variable RE, several attempts for methodological improvement has been taken in some European countries. As India is targeting for large scale RE integration, similar efforts need to be taken here as well. Challenges of RE integration for a developing country like India are unique, and they often include regulatory and social issues apart from technical ones. Likewise, methodological revision for RE planning activities should consider exclusiveness of the concerned energy system. The approach outlined in this article is an attempt to bridge the gap between short-term operation and long-term planning. The level of detail in the planning approach ultimately depend on the nature of system, availability of data, computational resource, and trained manpower for model development and maintenance.

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