Assessment of Wind and Solar Power Forecasting Techniques in SAARC Countries

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FOREWORD

Renewable Energy (RE) is becoming a major focus area for developing nations as their economies look to exploit opportunities for sustainable growth. Factors driving the growth of renewables have received significant attention across the sector of economy including academia, industry, policy makers and regulators. An increasing proportion of the demand will be met through variable RE sources such as wind and solar energy. However, the intermittent nature of wind and solar energy is a major hurdle in exploiting full potential of these clean and renewable energy sources. This hurdle can be overcome with accurate forecasting of wind and solar power. Therefore, accurate forecasting technologies are becoming an integral part of power systems running on wind and/or solar energy.

Forecasting primarily helps reduce the uncertainty associated with power generated from variable RE sources. Reduction of uncertainty will benefit all the stakeholders in the power sectors. This is especially true in the case of SAARC Member States, which are all at different stages of integration of variable RE sources in their power systems and markets. Consequently, forecasting systems in each of these countries are also at different stages of development. India and Sri Lanka are more advanced in their preparedness for higher penetration of variable REs whereas Afghanistan, Bhutan, Nepal and Maldives are at nascent stages. Pakistan and Bangladesh stand in the middle of the spectrum with sectoral advancements taking shape in recent years.

In this context, the SAARC Energy Centre has conducted this study on “Assessment of wind and solar power forecasting techniques in the SAARC countries”. A country-wise review of the power sector structure, meteorological prowess, existing electrical grid operation frameworks and existing forecasting systems is presented to identify the gaps and reveal the progress already made. Detailed analysis of all aspects of forecasting readiness is presented using a standardized scoring framework, which is used to quantify the status of wind and solar power forecasting in each SAARC Member State. This can serve as a self-evaluation tool for the Member States to help them know where they stand on the path to operational implementation.

For successful implementation of forecasting systems, it is recommended to adopt a collaborative approach towards stakeholder involvement and to bring all views onto a common forum for future cooperation and participation. Further, planning for the implementation of forecasting systems must cover all the requirements in detail, including requirements on types of forecasts, forecasting attributes, reporting, support and capacity building. Detailed guidelines provided in this report, covering all stages of forecasting system establishment, may be used for self-assessment and planning by each Member State. Country-specific recommendations, where applicable, have also been included for consideration of stakeholders.

(Dr Nawaz Ahmad)
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ABBREVIATIONS

Abbreviation	Full Form
ACAA	Afghanistan Civil Aviation Authority
ADB	Asian Development Bank
AEDB	Alternate Energy Development Board
AEMO	Australian Energy Market Operator
AEPC	Alternative Energy Promotion Centre (Nepal)
AI	Artificial Intelligence
AMD	Afghanistan Meteorological Department
ANN	Artificial Neural Network
ANPDF	Afghanistan National Peace and Development Framework
AREP	Alternate Renewable Energy Policy
ARIMA	Autoregressive Integrated Moving Average
ARMA	Autoregressive Moving Average
AWEFS	Australian Wind Energy Forecasting System
BERC	Bangladesh Energy Regulatory Commission
BMD	Bangladesh Meteorological Department
BPC	Bhutan Power Corporation
BPDB	Bangladesh Power Development Board
Can-CM4	Canadian Coupled Climate Model Version 4
CDGU	Centrally Dispatched Generation Units
CEA	Central Electricity Authority
CEB	Ceylon Electricity Board
CERC	Central Electricity Regulatory Commission
CMA	China Meteorological Administration
CMV	Cloud Motion Vector

Abbreviation	Full Form
CTBCM	Competitive Trading Bilateral Contract Model
CTU	Central Transmission Utility
DABS	Da Afghanistan Breshna Sherkat
DGPC	Druk Green Power Corporation Ltd
DGPC	Druk Green Power Corporation
DHI	Diffuse Horizontal Irradiance
DHM	Department of Hydrology and Meteorology (Nepal)
DHPS	Department of Hydropower and Power Systems (Bhutan)
DISCO	Distribution Company
DNI	Direct Normal Irradiance
DOM	Department of Meteorology (Sri Lanka)
DRE	Department of Renewable Energy (Bhutan)
DSM	Deviation settlement mechanism
DWD	Deutscher Wetterdienst
ECMWF	European Centre for Medium-Range Weather Forecasts
EPEX	European Power Exchange
ESSO	Earth System Sciences Organization
EWS	Early Warning System
FFS	Flood Forecasting Section
FiT	Feed-in tariff
FMI	Finnish Meteorological Institute
FNMOC	Fleet Numerical Meteorology and Oceanography Center
FnS	Forecasting and scheduling
FY	Fiscal Year
GCM20	Global Circulation Model run at 20 km Horizontal Resolution
GEM	Global Environmental Multiscale
GEOS5	Goddard Earth Observation System Version 5

Abbreviation	Full Form
GEPS	Global Ensemble Prediction Suite
GFS	Global Forecasting System
GHI	Global Horizontal Irradiance
GSM	Global Spectral Model
GW	Giga Watt
HPCS	High Performance Computing System
ICE	Inter-Continental Exchange
ICTP	International Centre for Theoretical Physics
IEA	International Energy Agency
IEX	India Energy Exchange
IFC	International Finance Corporation
IGCEP	Indicative Generation Capacity Expansion Plan
IMD	India Meteorological Department
INCOIS	Indian National Centre for Ocean Information Services
IPP	Independent Power Producer
IRBGS	Intermittent Resource-Based Generation Station
IRENA	International Renewable Energy Agency
ISO	Independent system operator
JICA	Japan International Cooperation Agency
KESC	Karachi Electricity Supply Company
KWh	Kilowatt hour
LCOE	Levelised Cost Of Energy
LDC	Load Dispatch Centre
LECO	Lanka Electricity Company
LTGEP	Long-Term Generation Expansion Plan
M&GC	Meteorological & Geo-Physical Centre
MAE	Mean Absolute Error

Abbreviation	Full Form
MBED	Market-Based Economic Dispatch
MEA	Maldives Energy Authority
MEW	Ministry of Energy and Water (Afghanistan)
MFD	Meteorological Forecasting Division (Nepal)
MISO	Midcontinent Independent System Operator
MME	Multi-Model Ensemble
MMS	Maldives Meteorological Service
MNRE	Ministry of New and Renewable Energy
MOEA	Ministry of Economic Affairs (Bhutan)
MoES	Ministry of Earth Sciences (India)
MPEMR	Ministry of Power, Energy & Mineral Resources (Bangladesh)
MW	Mega Watt
MWh	Mega Watt hour
MWSC	Malé Water and Sewerage Company
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NCHM	National Centre for Hydrology and Meteorology
NCMRWF	National Centre for Medium Range Weather Forecast
NEA	Nepal Electricity Authority
NEPRA	National Electric Power Regulatory Authority
NEPS	North East Power System
NISW	National Institute of Solar Energy
NIWE	National Institute of Wind Energy
NLDC	National Load Despatch Centre
NMAE	Normalised Mean Absolute Error
NOAA	National Oceanic Atmospheric Administration
NRMSE	Normalised Root Mean Square Error

Abbreviation	Full Form
NTDC	National Transmission & Despatch Company
NWP	Numerical Weather Prediction
PASA	Projected Assessment of System Adequacy
PE	Private Equity
PGCB	Power Grid Company of Bangladesh
PGCIL	Power Grid Corporation of India Ltd
PMD	Pakistan Meteorological Department
POISED	Preparing Outer Islands for Sustainable Energy Development
POSOCO	Power System Operation Corporation
PPA	Power Purchase Agreement
PRECIS	Providing Regional Climates for Impacts Studies
PV	Photo Voltaic
PXIL	Power Exchange India Ltd
QCA	Qualified Coordination Agency
R&D	Research and Development
RE	Renewable Energy
REC	Renewable Energy Certificate
REDF	Renewable Energy Development Fund
RegCM4	Regional Climate Model Version 4
REMC	Renewable Energy Management Centre
RIDS	Rural Integrated Development Service
RIMES	Regional Integrated Multi-Hazard Early Warning System for Africa and Asia
RLDC	Regional Load Despatch Centre
RMC	Regional Meteorological Centre
RMSE	Root Mean Square Error
RPO	Renewable Purchase Obligation
RTM	Real-Time Market

Abbreviation	Full Form
RTO	Regional Transmission Organisation
SAARC	South Asian Association for Regional Cooperation
SAPP	South African Power Pool
SCADA	Supervisory Control and Data Acquisition
SEC	SAARC Energy Centre
SEPS	South East Power System
SHS	Solar Home System
SLSEA	Sri Lanka Sustainable Energy Authority
SMS	Short Message Service
SREDA	Sustainable and Renewable Energy Development Authority
STELCO	State Electric Company Ltd
STU	State Transmission Utility
SWAP	Satellite Weather Application Platform
TSMS	Turkish State Meteorological Service
TSO	Transmission System Operator
TW	Tera Watt
UKMET	United Kingdom Meteorological Agency
UNDP	United Nations Development Programme
US	United States
USAID	United States Agency for International Development
WAPDA	Water and Power Development Authority
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting
WTG	Wind Turbine Generator

Data used in this Study

This study is based on a detailed primary and secondary research exercise. The primary research involved interactions with stakeholders (policy makers, federal bodies) of SAARC Member States to assess the status of wind and solar power forecasting, Renewable Energy (RE) penetration, policy targets for RE additions and government plans for augmenting RE forecasting systems. For all other data used in the report, information available in the public domain has been relied upon. The information provided in the report is limited to data available in the public domain and made available by the primary stakeholders.

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1 INTRODUCTION

1.1 Introduction to Wind and Solar Power Forecasting Globally

Electric utilities and transmission companies face variability and uncertainty in power demand and supply owing to several uncontrollable factors, which include sudden fluctuations in peak load and unexpected generation and transmission outages. Weather, in itself, is a major driver of power demand, where prolonged and/ or extreme weather events impact power demand and operation in generation. Variable energy generation introduces new sources of variability and uncertainty. This makes forecasting of variable energy all the more important. As wind and solar penetration levels increase, forecasting forms a critical component of operations.

1.1.1 Overview of Wind and Solar Power Forecasting Techniques

Wind and solar power forecasting involves several parameters, suited for different purposes. Some common types of wind and solar power forecasts are:

- **Weather forecast**: This involves monitoring weather data (temperature, pressure, surface roughness, and obstacles) and sending out weather alerts.
- **Day-ahead forecast**: This provides hourly forecast for the next few days, with refreshes every 6-8 hours. These forecasts are majorly used in unit commitment processes when system operators decide which generators will be dispatched on the following day. In countries with a must-run status for RE projects, system operators give dispatch instructions to thermal, gas and pumped hydro units in advance to avoid unnecessary starts and stops, which incur costs. For other countries also, wind and solar power forecasting is important for ensuring power system stability.
- **Intra-day forecast**: This provides generation values for typically 4-8 hours ahead, which are updated at least once in an hour. More sophisticated intra-day forecast systems refresh every 10 minutes. This forecast allows system operators to anticipate ramp events in generation and accordingly assess last-minute options like giving short-term dispatch instructions for balancing services.
- **Nodal forecast**: This aggregates the wind and solar power forecasts of each plant or generation area, using the methods mentioned above, into a singular forecast for each node or transmission delivery point. It can help in preventing transmission congestion and grid interconnection planning.
- **Persistence forecast**: It assumes that plant generation data will not change in the near future (next 1 hour or 1 day). The method further assumes that the conditions at the time of forecast will also remain the same during the tenure of 'persistence'. Persistence forecasts work only for a short time frame when weather patterns change very little. This is often accurate within the hour, but loses significance for higher time bands.
- **Ensemble forecast**: It is an aggregation of output from two or more forecast systems or methods. As no forecast type is perfect, several stakeholders rely on ensemble forecasts. This superimposes forecast data from different forecast systems and generates an ensemble, improving overall forecast accuracy, as weakly correlated forecast errors cancel out due to statistical smoothing.

Despite adopting several forecasting systems, model errors continue to persist. Using advanced statistics and machine learning algorithms, the stability and accuracy of systems have been significantly improved. However, no single model is accurate and replicable across geographies. Different models have to be compared, tested and evaluated to assess the right fitment.

Recent developments have been towards analysing uncertainty estimates and evaluating point forecasts, taking into account different forms of probabilistic forecasts, risk indexing and assessing different scenarios of wind and solar power generation. Probabilistic forecasts estimate uncertainty in solar and wind generation, expressed as probability measures (quantiles, interval forecasts, probability mass function, etc.). Risk indexing provides information on the expected level of forecast accuracy (predictability of weather or power generation) and a priori warning in the expected level of prediction errors. A combination of indices like the meteo risk index and prediction risk index, can be used for error aggregation and uncertainty representation. The third form of uncertainty estimation involves computation of prediction errors using a set of look-ahead times and modelling the spatial and spatial-temporal interdependence of forecast uncertainty.

At a holistic level, forecast systems have become more robust and are providing more accurate forecasts with the improvement in data, systems and enabling infrastructure.

Major weather, wind and solar power forecasting techniques used globally include:

- Physical modelling – Numerical weather prediction (NWP), remote sensing, local sensing
- Statistical modelling- Persistence modelling, time series modelling, AI-based approaches, etc.
- Advanced technologies-Satellite imaging, sky imaging, hyperlocal weather forecasting, Internet of Things application in forecasting

1.1.2 Rising Importance of Wind and Solar Power Forecasting

Wind and solar power forecasting serves several purposes. It enables power system entities to maintain lesser operating reserves. Improved forecasting helps reduce supply-side uncertainties and improve overall preparedness to handle unexpected events. Extreme changes in wind and solar generation and sudden changes in output (steep ramps) of power systems can be well contained through prediction. Most importantly, wind and solar power forecasting allows grid operators to schedule and dispatch generating plants efficiently and pre-empt costly grid balancing measures (reduction in plant efficiencies, buying costly short-term power, under-committing power plants even though they fall in economic merit order). Wind and solar power forecasting can help system operators make informed choices on power purchasing needs and ensuing transmission congestion.

Wind and solar power forecasting is not only important for grid operators; it can add value and improve decision-making capabilities of several stakeholders in the value chain. Power generators can undertake forecasting at the plant level to predict robust generation and thereby schedule maintenance activities when production is low. Energy traders and wholesale market participants can use wind and solar power forecasting data to anticipate day-ahead power market prices and place bids for trading, hedging or speculation purposes. Financial traders can anticipate and capitalise on price differences between day-ahead and real-time markets. Project financiers can use forecasting data to assess plant output and provide the necessary financing.

1.1.3 Major Factors in Assessment of Forecasting Techniques

While choosing wind and solar power forecasting techniques, stakeholders tend to prefer models with a high forecast accuracy. Several accuracy metrics like root mean square error (RMSE), mean absolute error (MAE) and critical success index are used to evaluate the efficacy of forecasting techniques.

However, no single forecast method is suitable for a system/ geography. Each forecast method has its own advantages and pitfalls, and therefore, its applicability tends to vary. Before adopting a forecast technique, the following needs to be assessed: (a) purpose of forecasting, (b) place/ area where the technique will be adopted (e.g., forecast methods for use at the system operator or grid node level will be different from those deployed at a RE plant level), (c) financial requirements (every forecast method varies in complexity and has its own prerequisites), and (d) cost-benefit analysis.

All forecast techniques rely on data, both past and present. Availability of large data, data systems and ancillary IT infrastructure will be a strong basis for selecting a method. Therefore, it is imperative to understand the infrastructure requirements and financial implications before deciding on a forecast method.

Also, the stakeholders need to evaluate the quantifiable benefits of adopting a forecast method and its impact on power markets. Benefits may rise from reduction in margin of error in forecast measurements, potential reduction in flexible operating reserve requirements, deferral in transmission and distribution investments through improved aggregation or reduction in imbalance costs by generators.

Typically, countries work on developing infrastructure, like robust weather systems, dynamic data gathering and build upon the infrastructure by adopting suitable forecast models. As markets improve and penetration of RE increases, forecast systems are augmented to model uncertain RE generation ranging from day-ahead forecasting to ramp forecasting. Several techniques are tested and their efficacy is measured to decide suitability.

New techniques are being developed using advanced statistical and machine learning models, to reduce forecast errors. However, a sophisticated forecast system/ technique may not always deliver the best results in a region/ geography. Therefore, suitability and applicability need to be ascertained taking into consideration parameters like representativeness, significance and relevance.

1.2 Framework Adopted to Execute the Study

The objective of the study is to: (a) assess the preparedness for wind and solar power forecasting techniques among SAARC Member States, (b) undertake gap analysis between the SAARC Member States and developed nations (that are higher up on the maturity curve in RE forecasting technique adoption), (c) recommend wind and solar power forecasting techniques that are best suited for the country in terms of objectivity and practicality, and (d) devise strategies for the implementation of the techniques. Governments, industry bodies, policy designers and collaborative groups have undertaken significant research and development (R&D) work over the years by. Several studies have been conducted and sophisticated methods designed to reduce shortcomings of existing techniques. The rapid growth in technology development and adoption has led to strong RE growth across the globe. However, development and deployment of RE forecasting systems has not been consistent. For example, while India (the most mature among SAARC Member States in terms of installed RE capacities) is the fourth largest and sixth largest wind and solar market in the world respectively (in terms of installed base), the country is still in the development stage when it comes to adopting forecasting techniques (weather, solar, wind). The other SAARC Member States lag in developing robust forecasting systems. Lack of technology adoption in a country can be attributed to several factors: (a) lack of precise/ accurate weather forecast models, which is the starting point in wind and solar power forecasting, (b) inadequate R&D, (c) non-accommodative policy/ lack of policy guidance and (d) other socio-economic challenges. The study strives to assess the status of each SAARC member state in terms of wind and solar power forecasting.

Forecasting of wind and solar power, when looked upon as the final outcome, requires a broad ranging foundational layer consisting of multiple components. The objective of this study is to cover all aspects of the components needed for establishing wind and solar power forecasting systems within the context of SAARC nations.

Accuracy of forecast serves as a measure of the efficacy of wind and solar power forecasting systems. As such, it is important to adopt a holistic approach towards setting up forecasting systems as accuracy of forecasts has greater dependence on base elements such as planning, infrastructure and meteorology, than on the models deployed.

1.2.1 Introduction to Forecasting

In an attempt to cover all aspects of the system needed for wind and solar power forecasting, this study begins with a context setting comprising the technical details of forecasting itself. Forecasting finds large application across multiple domains. The type of forecasting that finds utility in wind and solar power predictions is regression-based quantitative forecasting. Section 2.2 begins with an overview of the attributes of forecasting. This is necessary for introducing the terminology used in delving deeper into the technical aspects of the forecasting models. In addition to the attributes, categorisation of forecasts into different types are also detailed.

Following from the attributes and types of forecasting, a brief introduction to weather forecasting is provided as weather forecasts form a critical input in the forecasting of wind and solar power. This is followed by a comprehensive literature review on forecasting techniques. Wind and solar power forecasting are covered separately for this purpose. The exploration of every technique covered is associated with a quantification of the errors that may be expected. These quantifications are based on reviews of academic and professional publications selected on the basis of their technical quality and relevance. Experience of the authors in the field of wind and solar power forecasting plays a key role in the selection of publications reviewed and the categorisations of forecast models made. The following metrics are used in the quantification of 'expected errors':

A. Mean Absolute Error (MAE): A metric that identifies the average deviation from actuals of the forecast for any point of interest.

$$\frac{\sum_{i=1}^{N}|Actual(i) - Forecast(i)|}{N} \text{.....................} \textit{Equation 1}$$

B. Mean absolute percentage error: A metric that calculates the average deviation with respect to either the Actual values themselves or the capacity of the unit for which forecasting is done. MAPE is a more general metric that allows comparison between points of differing capacities.

$$\frac{\sum_{i=1}^{N} \frac{|Actual(i) - Forecast(i)|}{Actual(i)}}{N} \text{.......................} \textit{Equation 2}$$

C. Root Mean Squared Error (RMSE): Average of squared deviations of forecast from actual. RMSE as a metric penalizes large deviations more by virtue of squaring.

$$\sqrt[2]{\sum_{i=1}^{N}(Actual(i) - Forecast(i))^2} \text{.................} \textit{Equation 3}$$

D. Normalised Root Mean Squared Error (NRMSE): Normalized RMSE calculates the RMSE metric as a percentage of capacity which allows for cross site comparisons and is a standardized metric that can be applied to any set of forecasts and actuals from varied regions, capacities, etc.

$$\frac{\sqrt[2]{\sum_{i=1}^{N}(Actual(i) - Forecast(i))^2}}{Total\ Capacity} \times 100 \text{.............} \textit{Equation 4}$$

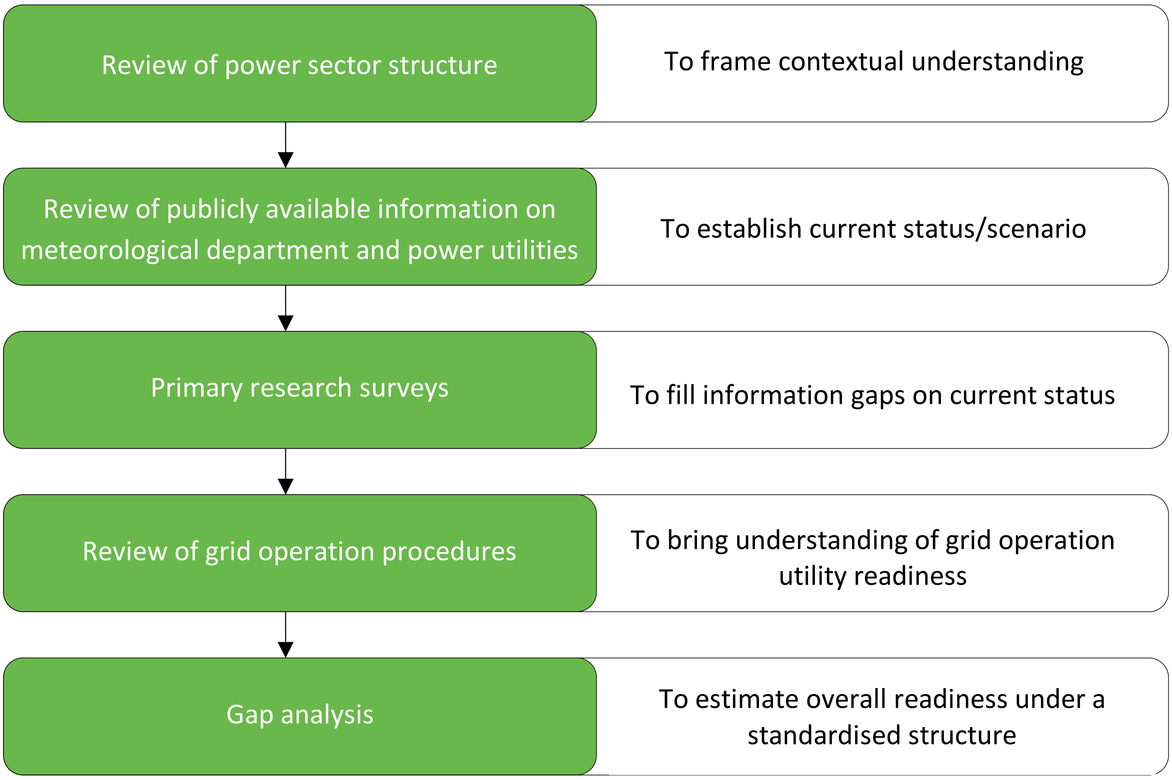
The coverage of techniques for wind and solar power forecasting is followed by a review of the existing wind and solar power forecasting systems globally. This aims to bring to the notice of the reader the existing state-of-the-art systems implemented internationally (mainly, in Australia and Europe) and the understanding of forecasting that can be drawn from such systems.

1.2.2 Current Status of SAARC Nations

Section 3 covers each of the SAARC nations over the topics of power sector structuring in the country, meteorology, regulatory scenario and the currently implemented state of wind and solar power forecasting.

In order to cover these topics, the information was gathered through survey questionnaires [included in Annexure (Section 7)] aimed at the meteorological agencies and the electricity grid operators of the countries. These primary research surveys were shared with the respective agencies/departments of the countries and the responses received formed the basis of the evaluation of each nation. Contextual understanding of the countries and their ambitions in wind and solar power have been gleaned from organisational reports of the government departments/agencies as well as from reports of multilateral agencies such as The World Bank, Asian Development Bank and International Renewable Energy Agency (IRENA). The grid codes of the countries, wherever available, have also been used as sources of information on operational aspects of electricity grid management in each of the countries. In cases where forecasting of wind and solar power has reached advanced stages of development, a deeper dive into the implementation of the forecasting system is provided.

The status setting is followed by a gap analysis of each of the countries in order to arrive at a standardised understanding of the readiness of each country in establishing state-of-the-art wind and solar forecasting systems. This is done through a scoring framework that assigns points for each aspect of forecasting. The overall score for each country gives a succinct view of the prowess and limitations of each country relative to each other. The scoring framework is also intended to provide a self-evaluation method through which stakeholders in the countries may make self-assessments, in the event they find inconsistencies in the findings and their own evaluations.



1.2.3 Challenges and Recommendations

Following the review of the current status of each country and the gap analysis, a broader perspective on forecasting systems is presented via discussion on the challenges faced in setting up forecasting systems. The multi-dimensional aspects of the challenges faced such as regulatory, technical, financial, implementation and operational are all covered.

It is important to note here that the focus in this section of the report has been on providing insights into the challenges faced in setting up forecasting systems at all stages rather than just focussing on the techniques or methods of forecasting. This is done in order to bring to attention the multi-faceted approach needed for successful deployment of forecasting systems. As alluded to earlier, the success of wind and solar forecasting systems is reliant on the successful implementation of the foundational layer focussing on planning, infrastructure and meteorology. If successfully implemented, the foundational aspects allow for flexible and fast paced development and application of multiple forecasting models adopting different techniques and incorporating inputs from several providers. This, based on analysis, should be the aim of any exercise devoted to the setting up of wind and solar forecasting systems. Towards this end, the various aspects ranging from policy requirements to information technology requirements have been covered in detail.

Further, a standard guideline has been developed with the intention of providing the relevant stakeholder, in each of the nations, a stepwise approach that may be adopted for establishing a forecasting system. These guidelines cover the initial decisions that need to be taken for setting up the systems and also cover the operational and implementation processes that need to be completed for successful deployment. For nations embarked on the journey towards setting up forecasting systems, the guidelines provided may be read only from the point of relevance to their specific scenario.

Along with the standard guidelines, country specific recommendations (Section 4.2) have been provided in order to assist stakeholders narrow down on focus areas, which, need attention as per the assessment of each country. The challenges faced, requirements needed, guidelines and recommendations have all been based on reviews of state-of-the-art systems as well as the SAARC nations' contemporary scenarios. More importantly, the real-world experience of the involvement in setting up forecasting systems has been drawn upon heavily to provide insights relevant to the topic of this study. This has been coupled with the primary and secondary research activities carried out over the course of the study.

2 WIND AND SOLAR POWER FORECASTING

2.1 Need for Wind and Solar Power Forecasting

This section discusses the needs for wind and solar power forecasting and how it can improve integration of RE in the grid, without compromising on grid security

2.1.1 Issues in Ensuring Stability and Security of grid

1. **Intermittency of renewables**: Renewables, majorly comprising solar and wind, have seen strong traction over the last decade. The primary challenge in this wide scale adoption of RE is its variable and intermittent nature, as supply of renewables is not round the clock and depends largely on diurnal and seasonal patterns. The rising share of RE in the overall power generation significantly cascades the problem. Intermittency is magnified while demand power dispatching becomes increasing difficult. Wind and solar power forecasting can aid grid operators in dealing with the intermittent nature of the technologies

2. **Dispatch rules giving precedence to RE**: In order to improve RE penetration in the overall power generation, several countries have given precedence to RE dispatching. This will help improve clean energy utilisation, thereby providing further fillip to the segment. The European Union (EU) provides for priority dispatching of electricity from renewable sources while India accords must-run status to RE plants. This guarantees access, dispatch, transmission and distribution of RE sources unless it poses an obstacle to system security. Several countries have put in place compensation mechanisms for RE generators in case generated power remains un-dispatched due to grid insecurities. Such measures need to be complemented by robust forecasting techniques such that curtailments are not arbitrary.

3. **Challenges in managing grids with high RE penetration**: RE generation is characterised by steep ramps due to sudden weather changes like cloud cover and windy conditions. Such variability in RE generation can be minimised to a large extent if RE generation systems are spread out geographically so that all plants are not impacted by weather changes simultaneously. In this way, variability from a large number of systems can be smoothed out. However, uncertainty and variability in wind and solar generation will continue to impact grid systems. Variability in RE generation will require additional actions to balance the system. System operators need to ensure availability of balancing systems to accommodate significant up and down ramps in RE generation. Grid systems also need to have flexibility though strong demand-side management, storage systems and grid interconnections. However, in several countries, power systems are still not equipped for high penetration of renewables. This leads to curtailment of RE sources. Curtailment happens when grid operators command facilities to reduce output to maintain system balance and reduce transmission congestion. RE curtailment typically occurs when plants generate excess electricity during off-peak hours which cause baseload power plants to hit minimum generation capacity. This, effectively, leads to reduced RE generation and missed economic and social benefits through production of cheaper and cleaner power. Forecasting can help predict uncertainties and allow RE as well as system generators to prepare better to tackle with the unpredictability.

4. **Deviations between schedule and dispatch**: Grid operators need to requisition power supplies from generating stations to match the demand load curve. The supply power pool tends to become more and more in-firm as variable generations from RE rise in the power supply portfolio. High renewable generation tend to change the timing of supply peaks, which may not be in line with the demand peaks. This is what is referred to as the “duck curve”, (illustrated in Figure 1)

which denotes the timing imbalance between peak demand and RE generation.

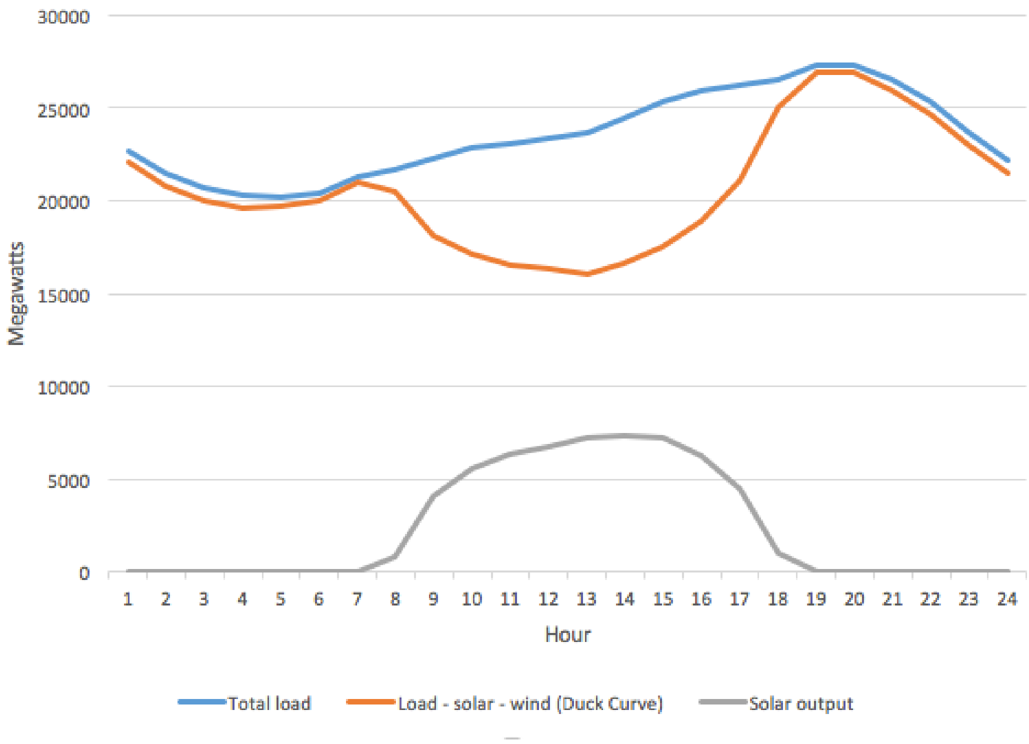


Figure 1: California Hourly Electric Load vs. Load Less Solar and Wind (Oct 22, 2016) (NREL)

Augmentation of RE needs to be complemented by strong forecasting and baseload as well as ancillary markets to digest the increasing 'duck's belly'.

2.1.2 Evolution of Deregulated Electricity Markets

A deregulated power market allows the entrance of competitors to buy and sell electricity through investments in power plants and transmission lines, as well as trading through power exchanges. This enables competition and increases consumer control over decision making. However, deregulation needs to be precluded by strong and mature power markets, through technology adoption, in order to allow price discovery. A key enabler for the same is sound forecasting techniques of power demand as well as supply.

1. **Importance of short-term load forecasting**: Exchange traded power majorly comprises short term power (day-ahead, term ahead, or real time). Power exchanges enable pooling of power from market participants and create liquidity through efficient trading and transactions. Short-term load forecasting is important for power producers which can enable them to optimise supplies and dispatch power to sellers at competitive marginal costs. Generators with storage options can additionally take advantage of peak power requirements and pricing premium by planning for economic dispatch.

2. **Price determination of short-term power**: Deregulated market enables consumers to purchase power at competitive prices, which are lesser than monopolist prices in a regulated market. In a perfectly competitive environment, producers try to sell power at lower marginal costs. In exchange-traded short-term power, buyers and sellers typically place bids and prices are determined based on auction mechanisms as set by exchanges. The right pricing needs to be

ascertained by sellers before putting out bids in order to foster transparent pricing and improve competition. This correct pricing can be ascertained if sound forecasting techniques are put in place to objectively deduce available supply position during peak and off-peak scenarios, and in turn, compute the marginal cost of supply. The right deduction of pricing will allow market participants to put in place winning bids, and thereby, enable transaction of more electricity through the market model.

2.1.3 Reduction in Dependency on Non-market Mechanisms for Short Term Power

1. **Ancillary services:** Ancillary services help grid operators maintain a reliable electricity system. These services, which go beyond generation and transmission, facilitate and support grid stability and security. With unbundling of generation, transmission and distribution, the vertically integrated electric utilities have been broken down to spur competition and transparency. Along with maturing of wholesale power markets, ancillary services have also moved towards de-regulation, where the system operator has to obtain ancillary services from other market participants and has no direct control over individual power stations. In a truly competitive ancillary market, power generators participate and system operators buy power in a spot market on a least-cost basis to correct frequency, voltage and other grid parameters. In developed markets like EU and USA, RE generators participate in ancillary services, thereby bringing down costs through aggregation of lower marginal cost projects. Such a system has to be precluded by sound forecasting techniques such that deviations between expected power production and actual dispatch is minimised.

2. **Deviation settlement mechanisms**: Deviation settlement mechanisms (DSM) is a regulatory mechanism by which grid stability is achieved by imposing penalties and incentives for over consumption/ injection or under consumption/ injection from the schedule as well as frequency variations. Due to the intermittent nature of wind and solar energy, forecasting and scheduling are essential for stable and efficient grid management. In India, several states have come up with DSM regulations, where, renewable generators are liable to pay fee for errors (or deviations) to the state/ regional DSM pools based on 15-minute time blocks.

Table 1: Deviation Charges for Solar Power for Gujarat (India)

Absolute Error in 15-Minute Time Block	Deviation Charges Payable
<=7%	None
>7% and <=15%	At 0.33 cents[1] per kWh for the shortfall or excess energy for absolute error beyond 7% and up to 15%
>15% and <=23%	At 0.33 cents per kWh for the shortfall or excess energy for absolute error beyond 7% and up to 15%; at 0.67 cents per kWh for balance energy beyond 15% and up to 23%

[1] $1 = INR 75.13 (as on July 13, 2020)

Absolute Error in 15-Minute Time Block	Deviation Charges Payable
>23%	At 0.33 cents per kWh for the shortfall or excess energy for absolute error beyond 7% and up to 15%; at 0.67 cents per kWh for the shortfall or excess energy for absolute error beyond 15% and up to 23%; at $0.01 per kWh for balance energy beyond 23%

Source: State DSM documents

Table 2: Deviation Charges for Wind Power for Gujarat (India)

Absolute Error in 15-Minute Time Block	Deviation Charges Payable
<=12%	None
>12% and <=20%	At 0.33 cents per kWh for the shortfall or excess energy for absolute error beyond 12% and up to 20%
>20% and <=28%	At 0.33 cents per kWh for the shortfall or excess energy for absolute error beyond 12% and up to 20%; at 0.67 cents per kWh for balance energy beyond 20% and up to 28%
>28%	At 0.33 cents per kWh for the shortfall or excess energy for absolute error beyond 12% and up to 20%; at 0.67 cents per kWh for the shortfall or excess energy for absolute error beyond 20% and up to 28%; at $0.01 per kWh for balance energy beyond 28%

For nations like India, where market-based balancing has not matured, DSM penalties continue to be a tool for system operators to enforce grid discipline among RE generators. This necessitates solar and wind developers to have strong forecasting measures in place to objectively forecast and declare day and week-ahead renewable power generation for each pooling station or each generating station. For the other countries, dispatch and integration of RE remains non-committal and no financial implications are imposed to check adherence.

2.2 Forecasting Techniques for Solar and Wind Power

Wind and solar power generation patterns are entirely dependent on weather phenomenon, namely, wind fields, insolation and cloud movements. This being the case, forecasting of wind and solar power generation patterns is primarily a function of forecasting the weather variables. The secondary layer in forecasting these patterns is based on utilising mathematical modelling of the physical characteristics of generation plants in order to formulate a method of conversion of the weather variables into power generation patterns, considering the relationships between weather and power outputs. Additionally, statistical methods may be applied to the data collected on power generation patterns and observed weather phenomena. This can improve the accuracy of the power generation forecasts through identification and correction of patterns in the errors observed in the primary weather forecasts.

Attributes

In order to better understand the different methods that may be used in the forecasting of wind and solar power, it is important to categorise forecasting by its different attributes. These attributes can be summarised as follows:

Table 3: Different Attributes of Wind and Solar Forecasting (NREL)

Type of Forecast	Features
Temporal horizon of forecasts	A quantification of the forward time duration for which a forecast is generated
Temporal resolution of forecasts	Indicates the time resolution of the forecast or the smallest unit time step for which a forecast value is generated
Spatial resolution of forecasts	Indicates the resolution in 2D space of the forecast values generated
Frequency of updates of forecasts	The number of times the process of NWP (a method for weather forecasting) is carried out to update the forecasts with newer forecasts

Of the above listed attributes of forecasts, the one that is most influential in deciding the techniques applied to wind and solar power forecasting is the horizon of the forecasts to be generated. This is so as the techniques that may be applied in generating a forecast are usually limited by the time horizon for which they are effective. The base layer for wind and solar power forecasting as stated earlier is formed by weather forecasts. The weather forecasts may be generated for a horizon of up to 10-15 days (short to medium range) going up to a few months ahead (long range). Forecasts for horizons greater than long range fall under the purview of climatological forecasting. For the purpose of wind and solar forecasting, the utility of the weather forecasts of different horizons varies by the use-case in consideration. For the purposes of planning and investing, long range forecasts serve valuable information. However, for the purposes of grid integration of wind and solar power and grid operations, the short and medium range forecasts are of much greater value.

Types of Forecasts

In addition to the forecast attributes, it is important to understand the different types of forecasts that may be generated for wind and solar power. These may be broadly classified as:

1. **Categorical forecasts**: They give a single descriptive prognosis of the future state of wind and solar generation variables or their contributing parameters. For example, a daily prognosis of wind power generation can be provided as 'high', 'moderate' or 'low'. Cloudiness, which is a critical parameter in solar power generation, is often provided as 'clear skies', 'partly cloudy' and so on.

2. **Deterministic time-series forecasts**: These are the most commonly used and widely available forecasts. They provide single power generation values for every time-step (as modelled in the time-series), which serve as a prediction for the actual power generation at those time-steps.

3. **Probabilistic time-series forecasts**: Probabilistic forecasts of time-series provide a quantification of the likelihood of occurrence of a given power forecast value. These are normally presented as

ensemble forecasts which provide a range of probabilities or confidence intervals around a deterministic forecast (the 50th percentile forecast).

Aggregation

Forecasting of wind and solar power may be carried out at different spatial scales which have influence over the accuracies that may be achieved in the forecasts. Weather patterns over larger spatial scales are more stable and at lower spatial scales (such as at a plant level) exhibit higher variability resulting from the localised terrain and its associated weather conditions. Plant level forecasts, when aggregated into area level forecasts spanning several hundred kilometres, result in much higher accuracies.

Forecasting Errors

Errors that arise from forecasting vary by region and the generation capacity for which forecasting is carried out. Aggregation of forecasts over larger geographical areas results in reduction of errors as well. In the following sections, expected error ranges for each of the wind and solar forecasting techniques have been provided based on a variety of studies. However, in order to provide context for the expected error ranges, it is important to consider the significance and impact of forecasting errors.

In regions with significant wind and solar capacities, normalized root mean squared error (NRMSE) values in the range of 5-7% can be achieved on a day-ahead basis and as low as 3% on a few hours ahead basis[2]. Based on data analysis, plant level forecast errors vary depending on the seasons, regional terrain and geographic positioning of generation plants. NRMSE values ranging from 5% to 30% have been observed on a few hours ahead basis.

The financial impacts of forecasts are linked inevitably to the accuracy of forecasts. In general, as the generation from wind and solar plants is variable, utilities hedge against in-firm generation by running reserve capacities. The benefits of forecasts then, can be financially quantified by estimating the reduction in requirements for reserve capacities and in associated costs.

Further, accurate forecasts have an impact on the merit order dispatch of generators. Accurate forecasts allow for treating wind and solar plants as sources which can be 'scheduled' to some degree. The degree of treating such generation as 'dispatchable' depends on the accuracy of forecasts, which consequently has an impact on the optimal scheduling of all generators. Studies simulating the cost reductions due to forecasting in American utilities (CAISO, ISO-NE and MISO)[3] have found reductions in generation costs ranging 0.22 - 4.47% (approximately $1 million to $23 million) for improvements in forecasts from 20% to 100%[4]. These studies assume different penetration levels and applicability of these results to any SAARC nations is dependent on the local characteristic of generation mixes and wind and solar penetration levels.

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[2]GIZ. Report on Forecasting, Concept of Renewable Energy Management Centres and Grid Balancing

[3] CAISO: California Independent System Operator; ISO-NE: ISO-New England; MISO: Midcontinent Independent System Operator

[4]Q Wang et al. The Value of Improved Wind Power Forecasting: Grid Flexibility Quantification, Ramp Capability Analysis, and Impacts of Electricity Market Operation Timescales. NREL

The following sections delve into the details of weather forecasting and wind and solar power generation forecasting methods for time-series forecasts, as these are the most useful from the point of view of power systems planning and operations.

2.2.1 Weather Forecasting

"Once the news could travel faster than the winds, then the winds need no longer come as a surprise." [Blum, Andrew - The Weather Machine]

Weather forecasting as a service started out historically as a pattern matching problem enabled by the telegraph system established in the United States. Following that, Robert Fitzroy in England introduced synoptic charts. The field of NWP was enabled by the theoretical discoveries of Norwegian meteorologist Vilhelm Bjerknes.

NWP is a method through which four dimensional simulations of the atmospheric and ocean systems are done by utilising observations of the state of the atmosphere at a given time to forward calculate the state of the atmosphere based on the Navier-Stokes and mass continuity equations along with the first law of thermodynamics and the ideal gas laws[5]. The process of NWP may be carried out repeatedly with small variations in state conditions to produce ensemble forecasts that form the basis of probabilistic forecasts mentioned above. The ensemble predictions are valuable for the prediction of wind and solar power generation as they provide a band of confidence around forecasts which may be used by the system operators to make better informed decisions of dispatch, grid management and power procurement.

NWP may be carried out at global or regional scales covering the entirety or parts of the earth systems, respectively. The computational and personnel requirements of carrying out global NWP demand intensive resource allocation, due to which such activities are executed by government meteorological departments/agencies dedicated to the prediction and monitoring of weather systems. These meteorological departments disseminate their weather forecasts freely or commercially for short to medium and long ranges, based on their capabilities.

2.2.2 Wind Power Forecasting

Wind power generation patterns have a very high degree of correlation with the wind field patterns. An accurate prediction of the wind fields coupled with physical modelling of wind turbine generators (WTGs) results in highly accurate prediction of wind power generation patterns, notwithstanding the impact of wake effects. However, every error in the prediction of wind patterns results in a significant error in wind power prediction owing to the cubic relationship between wind-speeds and power output of turbines. In order to curb the errors arising from wind field predictions, a host of methods may be applied to improve accuracies for the different forecast time horizons.

A common factor in the implementation of forecast improvement methods is the availability of observational data on weather parameters as well as power generation parameters. All forecasting frameworks are reliant on regular and robust data acquisition, and communication and storage systems.

[5]B. Peter et al - The quiet revolution of numerical weather prediction

The following paragraphs cover the different methods of forecasting that may be used for wind power generation.

A. Physical Models

Physical models are a mathematical estimation of the physical characteristics of the wind power generation stations. These must be accompanied by NWP, data which forms the basic input to the physical models.

Methodology

Physical models cover the modelling of each of the WTGs, including the manufacturer provided or observed power curves for WTGs spread over a given geographical area of interest. They also model any system parameters which affect power generation such as transmission and substation losses. The physical models in themselves are not sufficient to provide forecasts; as with any wind power forecasting models, and must be coupled with NWP data in order to generate forecasts. The errors that arise from physical models are largely errors in NWP which propagate forward as errors in power generation. The process of modelling the turbine generators begins with the mathematical equation giving the power output of a WTG:

$$P = 0.5 \times \rho \times A \times C_p \times V^3 \times N_g \times N_b$$ ……………………*Equation 5*

where,

P = Power output of a WTG

ρ = Air density in kg/m^3,

A = Rotor swept area (m^2)

C_p = Coefficient of performance

V = wind velocity (m/s)

N_g = generator efficiency

N_b = gearbox bearing efficiency

This equation leads to a power curve indicating the generation trend for any turbine given various wind-speed values. However, the actual performance of the WTGs is measured by the manufacturers and provided as power curves (e.g., as shown in Figure 2) incorporating the cut-in and cut-out wind speeds which can be used readily in the physical models to perform the wind to power conversions. The manufacturer provided power curves may even be replaced with power curves formed using observational data on power and wind speeds from WTGs in operation to give a more realistic conversion.

To take a more advanced approach, physical models can incorporate density adjusted power curves based on the most recent data and have different power curves for different periods of time in order to account for the variation in WTG performance.

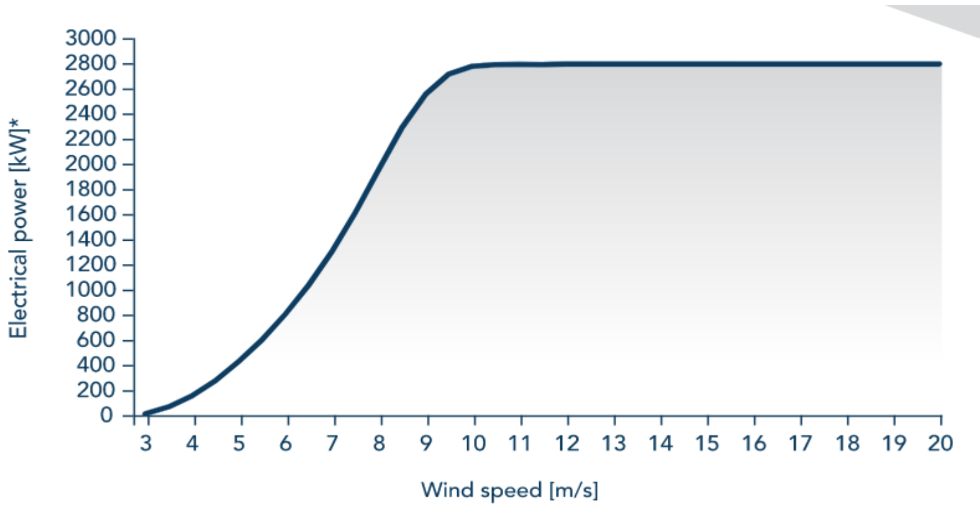

Figure 2: Suzlon S123 WTG Power Curve

Source: Power System Operation Corporation

Advantages

Physical modelling as a forecasting technique allows for conversion of NWP data into power forecast data, and as such, accrues the benefits of NWP data, viz., forecast horizons extending from short to long range. Only NWP data is able to capture long range patterns of wind fields that can be used in wind power forecasting.

Limitations

Given the dependence of physical models on NWP data, the advantages that accrue from it are also associated with the limitations that arise from using it. The set-up and operationalisation of NWP models for weather forecasting is a resource intensive and expensive process usually done by government meteorological agencies. Further, as the physical models only perform conversions of wind field patterns into power patterns, all errors that arise from NWP are directly propagated into errors in power forecasting with a cubic relationship between wind velocity and power output.

Expected Errors

Errors that arise from NWP models vary by terrain complexity and the models used for NWP. Quantifying errors for this methodology of forecasting must be done specific to the region of concern. In the ANEMOS studies carried out for Europe, Normalised Mean Absolute Error (NMAE) values ranging from 10% for simple terrain to 35% for complex terrain were observed for a 24 hour-ahead horizon[6]. Errors of 10% NMAE reflect high quality in forecasting and such errors at a site level may be easily managed by grid operators, however errors above 20% NMAE represent high variations between forecasts and actuals at a site level which may be compensated on aggregation.

B. Statistical Models

Statistical models represent the data based mathematical prediction models that identify relationships between data generating processes (assumed to be random processes) and utilise the

[6]Kariniotakis et all, What performance can be expected by short-term wind power prediction models depending on site characteristics?

learned relationships to estimate future values of the process. Statistical models encompass a wide range of models covering regression and categorical estimation models. All statistical models rely heavily on the data collected for observed variables of interest such as power generation, wind-speeds, wind directions and other weather variables. The most widely adopted categories of statistical models are detailed below:

Time-Series Models

Time-series models rely on the characteristics of a data generating process having some repeatability (seasonality), non-changing statistical properties (stationarity) and a persistence of trend (autocorrelation) with some time lag. In wind power forecasting, the Autoregressive Moving Average (ARMA) and Auto Regressive Integrated Moving Average (ARIMA) models have found significant usage.

Methodology

The ARMA and ARIMA models comprise two components, viz., the autoregressive and the moving average component. These are time-series models where the forecast output is based on its own past values. The autoregressive component of the model regresses with its own lagged, or prior, values. The moving average component incorporates the dependency between an observation and the residual error from the moving average model applied to lagged observations. The integrated component (in ARIMA) represents the differencing of raw observations in order to allow the time series to be stationary. The mathematical formulation of this is given as:

$$Xt = c + \epsilon t + \sum_{i=1}^{p} \phi i X(t-i) + \sum_{i=1}^{q} \theta_i \, \varepsilon(t-i) \text{........} \textit{Equation 6}$$

where,

p: the number of lag observations in the model

d: the number of times that the raw observations are differenced

q: the size of the moving average window

φ: the coefficient of Auto-Regression

θ: the coefficient of Moving-Average

ϵ: the random error at time t

c: the constant variable

The factor that differentiates between the ARMA and ARIMA models is the number of differencing steps that need to be carried out in order to make a time-series stationary (having a constant mean and variance.

Advantages

Time-series models have the benefit of being easy to implement, due to the requirement of only historical wind power observations to carry out forecasting. Further, the implementation of these models can be done without complex and expensive computational and software resources. These models exhibit good performance over the very short term (0-2 hours ahead) and short-range forecast horizons.

Limitations

The flipside of being easy to implement, time-series models lose performance benefits for time-horizons extending beyond repeatable patterns in historical power data. The variations in wind-field patterns seen overtime, extending beyond a few hours ahead, cannot be captured adequately by time-series models. The errors in forecasting resulting from the time-series models grow as the forecast horizon increases.

Expected Errors

In studies carried out for wind sites in the US, ARMA models gave an improvement over persistence forecasts (persistence forecasts used a reference to compare different models against where a persistence forecast is generated by using previous values of observed power as the forecast values for the next set of time period(s)) by about 3% for the one-hour ahead horizon and about 11% for a six-hour ahead horizon in RMSE terms.[7] For the case of wind-speed forecasting that can be used in lieu of wind-power forecasting, RMSE values of 1.6 were obtained for four-hour ahead forecasts, extending up to 2.3 and 3.3 for 10-hour ahead and 20-hour ahead horizons, respectively. Such numbers of 1-4% NRMSE on a 1 to 12 hour ahead horizon can be considered as best in class with variability expected from region to region. These short time horizons from a grid operations perspective are limited in their impact in the absence of real-time markets as is the case for all SAARC nations.

C. Artificial-Intelligence Models

Regression models based on Artificial intelligence (AI) models, such as Artificial Neural Networks and Support Vector Machines, have gained popularity in recent times with the improvements in data collection and increasingly inexpensive computational capacity gains. These models utilise data to learn from the past behaviour and make predictions with an underlying assumption that history tends to repeat itself. In the case of wind-power forecasting, such an assumption may be considered to hold true in the shorter timeframes and lose its validity, as the timeframe in consideration increases.

C.1. Artificial Neural Network (ANN) Models

ANNs serve as an easy-to-implement method for learning non-linear patterns from data. Recent advances in AI and computation have also enabled the implementation of deep-learning methods to be applied to very large datasets to learn the patterns of error that arise in NWP wind-field predictions and improve accuracies over short and medium range horizons.

Methodology

ANNs are a collection of mathematical modelling of neuron units, which are combined in multiple layers to form a network that can learn nonlinear relationships from data by iterative adjustment of 'weights' assigned to each neuron. A neural network in its most general form is a machine that is designed to model the way in which the human brain performs a particular task or function of interest. Each neuron in a neural network is governed by an activation function that processes the input(s) received by the neuron and converts it into an output.

[7] M. Milligan, et all. Statistical Wind Power Forecasting Models: Results for U.S. Wind Farms

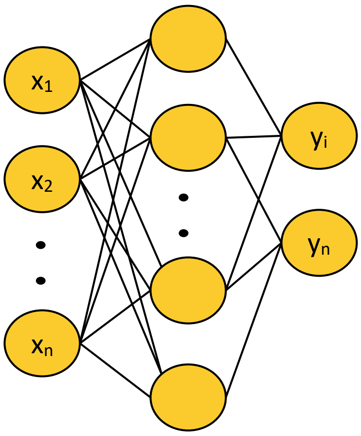

Figure 3: Structure of ANN

The learning process in the ANNs is essentially an iterative process, where a loss function is defined between the inputs and outputs of the neural network and the loss is minimised by updating the weights of each of the neurons at every iteration until a general solution is obtained. This process is called backpropagation.

Advantages

Neural networks carry the same advantages as the time-series models by being easy and quick to implement. Their performance over the short-range horizons is found in many cases to be superior to time-series models for the same range.[8] With the growth of open-source toolboxes and programming languages, the implementation of ANN-based models for wind-power forecasting is inexpensive.

Limitations

Similar to time-series models and other statistical techniques for forecasting of wind power, the accuracy of forecasts depreciates with an increasing time horizon for the same reasons; historical data is limited in its ability to provide predictive power and cannot serve as an alternative to the NWP models that simulate the weather phenomenon driving wind power generation.

Expected Errors

In forecasts carried out for wind speeds using ANNs exclusively, RMSE values of 0.54 were observed for five-hour ahead horizons. For 10-hour and 20-hour ahead horizons, the RMSE values observed were 0.79 and 1.1, respectively, which are significantly better than those achieved by time-series models for the same ranges[9]. RMSE values in the range of 0.5 to 1.1 for wind-speed forecasts represent very good levels of accuracy and the translation to power forecasts would result in accuracies that are sufficient for successful utilization in most grid operation activities.

D. Hybrid Models

Hybrid or mixed models use a combination of the different types of models described above to create forecasts of wind power. These types of models are the most commonly implemented and researched,

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[8]M. Milligan, et all. Statistical Wind Power Forecasting Models: Results for US Wind Farms

[9] Alencar et al. Different Models for Forecasting Wind Power Generation: Case Study. Energies. MDPI

due to their superior performance over physical, statistical or AI models implemented independently.

Methodology

Given the vast amount of work done on wind-power forecasting using the different combinations of models, there is no single method that may be applied to achieve the best possible results for any given region or timeframe. A large-scale study for wind power forecasting in Europe, called the ANEMOS project, found that "none of the models could perform better than the others for each test case or look-ahead time". The combinations of models can be classified into the following:

- Combination of physical and artificial intelligence approaches
- Combination of statistical and artificial intelligence approaches
- Combination of alternative artificial intelligence models

Figure 4 illustrates the components of a hybrid model that may be used in partial or full combination.

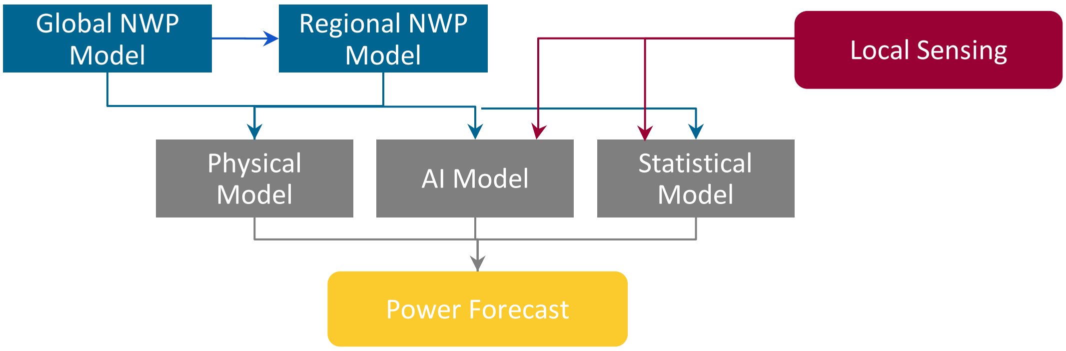

Figure 4: Components of Hybrid Model

Advantages

As hybrid models encompass combinations of the other different types of models, they bind together the advantages of other models and, as a consequence, offer better performance and reliability than the rest of the models independently. These models can combine the superior performance of the AI models in short-range horizons and the performance of the physical models over medium and long-range horizons.

Limitations

As hybrid models represent an infinite number of possible combinations of models, development of hybrid models to achieve the best possible forecast performance requires dedicated focus for the region of interest and a time-consuming process of development and testing, which, while beneficial in performance terms, is more resource-intensive than other models described above.

Expected Errors

Errors in forecasting observed with the use of hybrid models vary by region and implementation. In the US, NMAE (Normalized Mean Absolute Error) of 10-15% have been achieved on a 24-hour ahead horizon and about 5% on a few hours-ahead horizon. For individual wind sites, operators in Ireland have given accuracies of 10-20%. These numbers represent the general errors achieved on average in multiple regions by multiple providers and give the range for best possible accuracies. Improvement and degradations in accuracy may be expected depending on the region-specific characteristics.

2.2.3 Overview of Operational and Commercial WPF Systems Globally

Wind power forecasting has received significant attention from electric power utilities and research programmes, both academically and via concerted governmental programmes. Over years, the progress of forecasting of wind and solar power and its effective application has led to commercial mechanisms, which have allowed for growth of private enterprises in forecasting. There are several private forecasting companies across the world delivering services to private generators and utilities. The power utilities (system operators) opt for utilisation of private forecast vendors or generate their own forecasts or a combination of both. For the purpose of this study, the wind power forecasting systems of Australian Energy Market Operator (AEMO) are discussed in detail, followed by an overview of some European wind power forecasting systems that have been developed by research groups.

A. Australian Wind Energy Forecasting System (AWEFS)

The Australian Energy Market Operator (AEMO) is mandated under the National Electricity Rules of Australia to generate wind energy forecasts to manage the dispatch activity for all semi-scheduled and unscheduled wind generators. AEMO follows a forecasting system of assessing their system's ability to meet the dispatch requirements through a Projected Assessment of System Adequacy (PASA) process. The forecasting done under this system is tabulated in Table 4.

Table 4: Forecast Systems under AWEFS

Forecast Horizon	Inputs	Frequency of updates	Resolution
Dispatch	5 min	5 min	5 min
5 Minute Pre-Dispatch	2 hours	5 min	5 min
Pre-Dispatch	Up to 40 hours	30 min	30 min
Short-term PASA	8 days	30 min	30 min
Medium-term PASA	2years	Daily	Daily

Source: AEMO - AUSTRALIAN WIND ENERGY FORECASTING SYSTEM (AWEFS)

To carry out forecasting for the multiple horizons, AEMO utilises inputs on both the static information of wind generators and the dynamic data comprising data collected by SCADA systems and the NWP data. The collection of static data is done by AEMO through a standard format, called 'Energy conversion model', comprising historical local sensing data, WTG manufacturer information and some details of the layouts of the wind sites.

Wind power forecasts for all time horizons are generated for: (a) individual wind farms; (b) regional aggregates of wind farms; and (c) full control area (NEM) aggregated wind capacity. These forecasts utilise the static and dynamic input data in different combinations as detailed in Table 5:

Table 5: Wind Power Forecasts across Horizons

Forecast Horizon	Inputs
Dispatch	• Active power generation (MW) • Wind farm control system set-point • No. of turbines actively generating • No. of turbines available to generate • Wind speed observations (SCADA) • Wind direction observations (SCADA) • Ambient temperature observations (SCADA)
5-minute pre-dispatch	• Active power generation (MW) • Wind farm control system set-point • No. of turbines actively generating • No. of turbines available to generate • Wind-speed observations (SCADA) • Wind direction observations (SCADA) • Ambient temperature observations (SCADA)
Pre-dispatch	• Wind speed forecast (NWP) • Wind direction forecast (NWP) • Ambient temperature forecast (NWP) • No. of turbines unavailable for generation • Active power injection limit
Short-term PASA	• Wind-speed forecast (NWP) • Wind direction forecast (NWP) • Ambient temperature forecast (NWP) • No. of turbines unavailable for generation • Active power injection limit
Medium-term PASA	• Climatological data • No. of turbines unavailable to generate • Active power injection limit

These forecasts are used by AEMO for multiple operational and planning activities, such as available capacity assessments, reserve capacity assessment (in combination with demand forecasts) and for market-based dispatch activities.

B. Prediktor

Prediktor is a physical modelling system for wind power forecasting, which was developed at the Riso National Laboratory in Denmark. This system has a high dependence on NWP data, which is sourced from the HIRLAM model[10]. The wind speed and wind direction variables from the NWP data are corrected for turbine heights and local terrain effects and converted into power output forecasts using physical turbine modelling and a modelling of the wake effects. Model Output Statistics (MOS), which is a common statistical technique for bias and error correcting of NWP data by using observational data, where available, is also applied in Prediktor. Prediktor was tested in Iowa and California in the US and in Ireland.

C. WPPT

The Wind Power Prediction Tool was developed by the Technical University of Denmark (DTU). The WPPT system was operational in the western part of Denmark (Energinet) as of 2009 and was tested for a one-year period at Hydro Tasmania in Australia[11] as well as in Ireland.

The WPPT system is capable of forecasting for individual and collections of wind farms as well as for an entire region. In this system, observational data is used only from a few reference wind farms which serve as a proxy for the calibration of forecasts for other nearing wind farms. The inputs to the system are:

- NWP data for the region
- NWP data for the reference wind farm sites
- Wind power generation observational data (SCADA power data)
- Static data on all wind farms
- Aggregated energy readings from all wind turbines

The system uses the NWP data along with physical models of the wind farms at a plant level and applies calibrations to the resulting power forecasts through statistical techniques. The wind from forecasts is up scaled to a sub-area level using a function that is dependent on the NWP for the area. The sub-area forecasts are further upscaled to area-level forecasts and finally a total regional forecast is derived through a time-dependent weighted-averaging process.

2.2.4 Solar Power Forecasting

Solar power generation patterns maintain a linear relationship with the insolation incident on the solar panel array installed at the generation plant. To capture the power-generation patterns, a numerical prediction of the global, diffuse and direct insolation values is fundamental. The variations in the insolation patterns and hence the generation patterns arise over two horizons. In annual durations, there is seasonal variation in the levels of insolation received on the earth's surface due to the varying distance from the sun of the location in consideration. Over shorter durations of the order of a few hours or a few days, the variations in solar insolation arise due to the interruption of the incident solar radiation as a consequence of cloud movements. The variations that arise to astronomical seasonality can be accounted for in a straightforward manner through the mathematical modelling of the solar system and accounted for in the physical models of solar power generation forecasting. However, the

[10]HIRLAM. http://hirlam.org/

[11]Nicholas Cutler, Kieran Jacka, T. S. Nielsen, and Merlinde Kay, "The First Australian Installation of the Wind Power Prediction Tool," in Proceedings of the Global Wind Energy Conference, Adelaide, Australia, Sept. 18–21, 2006

prediction of short-range variations in solar power generation, due to cloud movements, is a more challenging activity and relies on additional information collection via satellite remote sensing and hardware installations.

A. Physical models

Methodology

Physical modelling of the solar power generation plants requires a mathematical modelling of the characteristics of the solar panels installed at the plant taking into consideration the system design characteristics specific to each plant, such as the type of plant (fixed PV, single axis tracker, double axis tracker), the orientation of the plant (varies by location of installation), the tilt angle and so on. Once these design parameters have been modelled, it is possible to transform the insolation on the surface of the earth to incident insolation on the surface of the solar panels. It is also possible to model the solar power generation stations at a PV cell level, considering the different types of PV cells that may have been used at any given solar generation plant (e.g., monocrystalline, polycrystalline), however no clear advantage of using complex models has been found due to the fact that the source of error in power forecasting will result from the errors in NWP data in both the cases. The surface insolation predictions from NWP models coupled with the physical modelling of the solar generation plants can be deployed for forecasting the power generation patterns at short-, medium- and long-range horizons. Similar to the case of wind power forecasting, the use of physical models for solar power forecasting results in all errors from NWP resulting in errors in power forecasts. However, in the case of solar, since the relationship between panel incident insolation and the power generation is a linear one, as seen from Figure 5 for a sample plant from India, the error propagation is also linear unlike the cubic relationship of wind speed to power error propagation.

Advantages

Physical models for solar power forecasting hold the advantage of not needing any observational data to set-up the models for forecasting. For clear-sky days, the physical models provide almost perfect forecasts as the relationships between incident photons on the panels and their consequent current and voltage outputs can be modelled with a high level of precision. Setting up and operationalization of physical models is an inexpensive and quick way to establish forecasting even in the absence of observational data. However, this approach requires NWP data which, as explained in earlier sections, is a resource intensive and expensive capability to build. Although sourcing of NWP data from external sources may be done at relatively low costs.

Limitations

Similar to the case of wind and as mentioned above, the errors in NWP data cannot be accounted for by the physical models. As a result, the errors in solar power forecasting using physical models will not be sufficient to cover the high-frequency variations seen in power output due to cloud movements.

Expected errors

Errors observed in solar power forecasting vary by the source of NWP data and by the location for which forecasting is done. Island nations generally are beset by more frequent cloud movements and unpredictable rains, which make forecasting less accurate in such regions. NRMSE values of 11-12% were observed by a study done for a 1 MW plant in China. Errors of 10% were observed in a study of physical models forecasting using NWP in the EU. For the case of performance of physical models using measured solar irradiance data (in place of NWP), errors were found to be 0.5% NRMSE, indicating the good performance of physical models in conversion of weather variables to solar power output. These results indicate that all of error from physical models may be attributed to the errors in NWP. A range of 10-15% represents a high quality of NWP forecast data if cloudy days are considered in the evaluation sample. For clear sky days, errors of 10-15% represent very high errors and likely poor physical modelling of the solar plants.

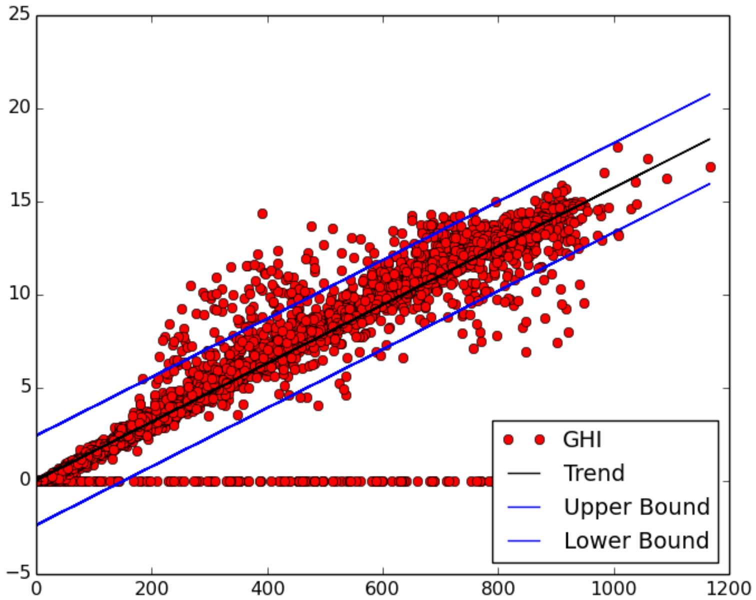

Figure 5: Relationship between Panel Incident Insolation and Power Generation

B. Statistical models

Statistical models for solar power forecasting follow in the same vein as the ones described for wind power forecasting where the data from observed parameters is incorporated into models mapping the relationship between the dependent and independent variables in order to find correlations and error patterns that can be forecasted with a higher accuracy. Statistical models may also incorporate additional data sources that capture cloud presence and movements such as those detailed in the following section which would allow for even higher accuracies in forecasting the variations in generation.

B.1. Time-series models

As detailed in the section covering wind power forecasting earlier, the time-series models have found effective application in the very-short- and short-range horizons for solar power forecasting. In the case of solar power forecasting, the short-term variations that arise from cloud movements can be better captured through time-series modelling of the consequent ramps in generation. Time series models or regressive models can be further classified into linear stationary models, linear non-stationary models and non-linear stationary models depending on the characteristics of the time-series as described in the earlier section on wind power forecasting using time-series methods.

Advantages

Time-series models can be used to generate solar power forecasts for short range horizons and are easy and inexpensive to set-up. With the existence of multiple open-source solutions for creating time-series models of all types, the skilled personnel requirements also present a low barrier. Since these models used exclusively do not require NWP data, the costs involved in acquiring NWP data are also exempted.

Limitations

Since time-series models do not utilize NWP data and rely only on the solar power output data for forecasting, the forecast horizons are limited to the very short and short range as the variations that arise in the medium to long term require at least one exogenous variable (solar insolation) to be included in the models.

Expected Errors

For studies done in the US, NRMSE values of 19% were observed at one hour ahead horizons and 28.8% at two hours ahead horizons indicating the variability seen across geographies when compared against the results seen for physical models in the China region. Errors of 19% and 28.8% NRMSE of one and two hours ahead horizons indicate the difficulty in the sample sites as the variability in generation due to cloud impacts can be assumed to be very high. In such conditions, given the horizons are very short term, there is scope for better accuracies through the use of other methods and indicate a limitation of time-series models for solar forecasting. In terms of utilization of forecasts, the accuracy levels seen here may be sufficient depending on the size of the plants at which such accuracies are achieved and the level of aggregation done. For larger capacities (i.e. 10% of overall generation and more) NRMSE numbers above 7-10% would be insufficient for grid operations activities.

B.2. Artificial Neural Networks (ANNs)

ANNs as described in section under wind power forecasting techniques are a method of learning statistical relationships between variables. In many cases, ANNs are thought of as a black box approach to learning patterns where a mapping between inputs and targets (expected outputs) is used to generate forecasts. In the case of solar power forecasting, ANNs may be used as regression models to predict numerical values of future power generation given a dataset containing past generation values.

Advantages

ANNs represent an easy to implement and inexpensive solution to forecasting for the short to medium term horizons. Similar to time series and physical models, a host of readily available open-source solutions exist which make the process of forecasting using ANNs relatively less skill intensive.

Limitations

Given the modular nature of ANNs at a conceptual level, the performance of ANNs for any given location is dependent on the skill of the modeller and the availability of observational data. Multiple variations of ANNs can be used for solar power forecasting and their accuracies may suffer due to either insufficient modelling or more likely, a lack of historical observational data which may be used for training of the ANNs. This makes ANNs a poor solution in implementing forecasting for newly commissioned plants.

Expected Errors

For the same study done in the US, as stated for time-series models, ANNs were able to achieve 15.8% and 25.6% NRMSE at one and two hours ahead horizons respectively. With additional modelling using genetic algorithms, the NRMSE values were 13% and 18.7% for one and two hour's ahead horizons. These numbers represent much improved accuracies from the time-series models and are representative of above average accuracies without the use of higher end technologies such as cloud movement monitoring. Variations in the errors are largely dependent on the local weather at the site of interest and cannot be used as a reference to other sites if the regions differ in their atmospheric behaviour.

C. Hybrid Models

Hybrid models for solar power forecasting have been widely researched and implemented across countries. The variations in hybrid models come from the different combinations of models used and the input data used for the models. A variety of weather variables such as wind-speeds, rainfall and temperature have been used in addition to solar insolation variables (GHI, DNI and DHI). Combinations of Recurrent Neural Networks, Long Short-Term Memory Networks (types of ANN), time-series models, ANNs and machine learning techniques such as Support Vector Regression have been used for solar power forecasting over many geographies and time horizons.

Advantages

Hybrid models being a combination of other models leverage the benefits of statistical models in the superior accuracy over short and very short-term horizons and also accrue the benefits of the physical models over medium- and long-term horizons. Hybrid models also often achieve higher accuracies over all horizons.

Limitations

Similar to the case of wind power forecasting, since they represent an unending array of model combinations that are possible, performance of hybrid models is dependent on the skill of the modeller and require domain expertise to implement well.

Expected Errors

For a 24-hour ahead horizon, accuracies ranging from 2.74% to 4.65% NRMSE were achieved by advanced modelling methods including Radial Basis Function Neural Network, Multiple Linear Regression. On hourly forecast horizons, NRMSE values range from 9.4% to 18.34% depending on the input variables considered and the type of modelling. These variations in accuracies show the dependence of hybrid models on the modellers and more importantly on the geography of the solar plants for which forecasts are done. As discussed in the previous section on time-series models, NRMSE numbers below 10% at a plant level and even at a significant aggregation level represent sufficiency in forecast accuracy dependent on the region. However, generalizations on these accuracy levels cannot be made without consideration to the specifics of the generation plants at which forecasting is done and the level of aggregation in capacity possible for grid management.

D. Specialised Cloud Models

Since the variability in solar power generation is linked inextricably with the cloud patterns and movements, attempts to forecast the solar generation patterns accurately must account for cloud patterns and movements. However, as the cloud movements are a highly localized and changing phenomena, NWP models fail to capture the specificity of patterns observed. To counter the lack of accuracy in cloud pattern and movement prediction through NWP models, additional techniques have been adopted based on two prominent methods.

Sky Imaging Systems - These are hardware systems that visually capture the cloud patterns as seen over a solar site at repeated intervals and the associated software converts the captured images into time-series patterns of percentage sky coverage. The images as well as the converted numerical data generated by the sky imaging systems can be incorporated into statistical as well as time-series models to achieve higher accuracies in solar power forecasting by better predicting the changes in generation due to cloud movements.

Cloud Motion Vectors - Cloud Motion Vectors (CMVs) capture the cloud movements at a very large scale through the use of data captured by remote sensing satellites. The satellite data is used to detect the presence of clouds of varying density at different vertical levels and application of algorithms over multiple such data snapshots results in the generation of CMVs which estimates the future positions of the clouds based on their recent previous positions and velocities. CMVs may be incorporated into statistical models for solar power forecasting or independent models may be applied exclusively to the CMVs to forecast the sky coverage due to clouds at a particular location.

Both sky imaging and CMV methods are applicable to the process of solar power generation forecasting at very-short range horizons (0-2 hours ahead) as the persistence of cloud behaviour is time limited. Adoption of these methods is not widespread as the economic viability of such applications is not always justified.

Advantages

The advanced models described above have the advantage of utilizing additional information otherwise unavailable in other methods. This gives such models the benefit of higher accuracies in the very short- and short-term horizons. The accuracy gains are not only in terms of the standard metrics utilized in assessing forecasts but also help in predicting ramps accurately which are of great benefit to the grid operators when the penetration of solar power increases to grid affecting levels.

Limitations

The highly specialized and often hardware dependent methods, while adding to the accuracies achieved, also require significant expenditure on setting up of the hardware and image processing and data analysis software for inclusion of the additional information into forecasting models. These techniques provide increased accuracies only at very short- and short-term horizons and add no value for medium to long-term horizon forecasting.

Expected Errors

Limited studies have been done utilizing satellite imaging to include information from cloud motion vectors into solar power forecasting. For predictions of GHI, errors of 40 W/m2 have been attained[12] in comparison to 100 W/m2 achieved by persistence methods. These results are on the primary input basis of the weather parameter needed for solar forecasting i.e. Global Horizontal Irradiance (GHI). The relationship between GHI and power output of a solar plant being linear, the errors can also be assumed to propagate linearly whereby a 60% reduction in error in GHI can be translated as a 60%

[12]A Hammer et al. SHORT-TERM FORECASTING OF SOLAR RADIATION: A STATISTICAL APPROACH USING SATELLITE DATA. Solar Energy. Elsevier.

reduction in error in power forecasts. For a network of sky imaging systems at UC San Diego[13], binary predictions on the type of cloud patterns (cloudy/clear-sky) were done correctly 70% of the time on a now casting basis (0-1 hour ahead).

2.2.5 Overview of Operational and Commercial SPF Globally

Solar power forecasting has also been a mainstay of research and operational attention by electric power utilities. Large solar power penetration brings with it challenges similar to wind power, but even more pronounced in many cases, as the variability of solar power due to cloud movements is drastic and requires action and planning by grid operators at a fine scale. An adjacent system to the AWEFS by the Australian Energy Market Operator's (AEMO) for solar forecasting is reviewed here. The system is referred to as the Australian Solar Energy Forecasting System (ASEFS).

A. Australian Solar Energy Forecasting System (ASEFS)

ASEFS is designed to generate solar power forecasts at time horizons ranging from 5 minutes ahead to 7 days ahead. The development of ASEFS was done in two phases:

Phase 1: The first phase of the system was developed to meet the requirements arising from solar power generation by utility scale plants (30 MW or higher). The first phase of the system is configured to generate forecasts for the Dispatch, 5-minute Pre-Dispatch, Pre-Dispatch and the Short Term PASA time horizons. Inputs used in this phase of the system include NWP data, SCADA-based observational data, along with the standard static data as used in the wind power forecasting system (AWEFS). In addition, specific to the solar forecasting system, images from the Japanese satellite (Himawari-8) are used in the forecasting system to incorporate cloud movement patterns.

Phase 2: The second phase of the system was focussed on incorporating forecasts for the distributed solar generation capacity at a small scale (100 kW or lower), which when aggregated could contribute to a significant capacity overall. This phase of the forecasting system is designed to forecast for only the pre-dispatch and short-term PASA time horizons.

As the second phase is restricted to forecasting for very small-scale solar power generation systems, which may be mounted on rooftops of residential and commercial dwellings, collection of observational data from every system is not feasible. As a consequence, forecasting for this phase of the system is reliant on observational and static data from some selected systems along with NWP data (multiple vendors) and Himawari satellite data. The satellite data is also used to assessing the total actual power generation by conversion of solar insolation observations from satellite images to power output for the aggregate capacity of total installed small-scale solar power generation systems.

2.3 Global Case Studies

The section encapsulates the cost implications for a nation to integrate RE into the grid. Subsequently, it includes case studies stressing upon the financial benefits of having RE forecast systems. The section also brings out examples of wind and solar forecasts that are currently used across the world while

[13] C Chow et al. Intra-hour forecasting with a total sky imager at the UCSan Diego solar energy testbed. Solar Energy. Elsevier.

further illustrating the forecasting ecosystem in each of the countries under different power market designs and institutional frameworks.

2.3.1 Financial Implications for Dealing with High RE

Forecasting RE generation precludes scheduling and grid integration of RE. Globally, several countries like USA, China, the UK and European Nations like Germany and Denmark have seen strong growth in renewables over the last decade.

Improving Forecasting Systems

The field of solar and wind output forecast is still evolving, with major improvements still possible in the space. Several studies have assessed that reducing short term forecast errors to half over the next 10 years is realistic. As per estimates, this can reduce integration costs of wind by 42%[14]. The study, conducted in 2014 assumes a forecast error of 15% of installed wind capacity 4 hours before real time and proposes a reduction to 10% post 2020 and 6% thereafter.

A. **Case of Germany**

The National Grid of Germany aims for 3.25%-4.75% accuracy in its day-ahead wind energy forecast and the German TSO states that actual wind output deviates by 2% RMSE from day-ahead forecast[15]. This imbalance has led to different market mechanisms in the form of reserve requirements and balancing markets. All this, in turn increase system integration costs and overall system operation costs. Congestion management costs (minimizing the throttling of electricity fed in from RE sources and ensuring flexibility in the system) has been increasing in the country since 2009. (Figure 6).

Estimates by Fraunhofer Institute for Solar Energy Systems state that costs of national congestion management in Germany presently exceed 1.4 thousand million euros in 2018. Subsequently, ~10,200 GWh was curtailed while ~10,238 GWh of reserve power was ordered to stabilise the grid. The major reasons for the rise in congestion charges can be attributed to powering down of a few nuclear plants, the large addition of wind capacities, delays in grid reinforcements and forecast errors in load and VRE output.

B. Case of the United Kingdom

Renewable energy sources have grown from 5.46 GW in 2010 to 48.5 GW in Q2, 2020. Britain's short-term balancing and grid congestion management is conducted through balancing mechanism. The costs for congestion management are socialised via the Balancing Services Use of System (BSUoS) charge, which is paid for by all suppliers and generators on a pro rata basis. Britain's constraint costs from £86 m p.a. during 2005–08 to £303 m during 2014–17. Constraint costs have risen on average by £22.7 m per year over this period, or by £5.8 m for each TWh generated by wind. Curtailment, on the

[14]https://www.theccc.org.uk/publication/value-of-flexibility-in-a-decarbonised-grid-and-system-externalities-of-low-carbon-generation-technologies/

[15]https://www.tagesspiegel.de/wirtschaft/energiewende-80-prozent-erneuerbare-sind-kein-problem/13688974.html

hand, has been high. In fact, individual farms ranged from 0% to 32% of their annual output curtailed, depending on their location and operator preferences[16] (Refer to Figure 8)

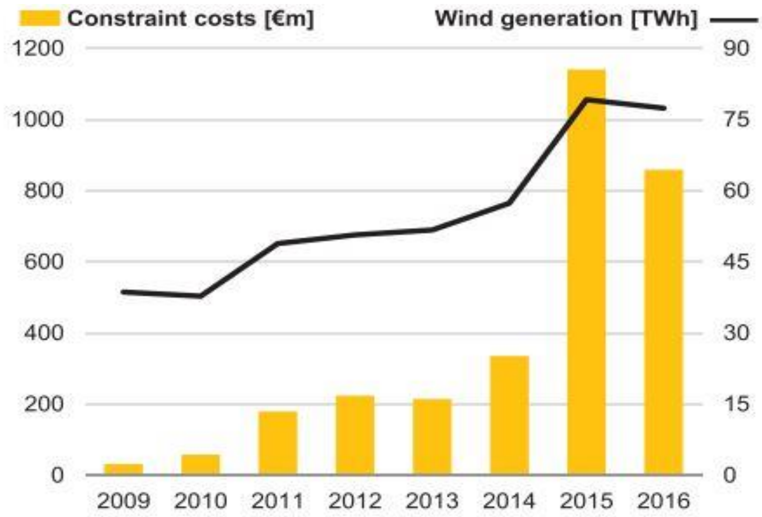

Figure 6: Constraint Costs for Germany

While total balancing costs and contracted reserve capacities have fallen owing to developments in German balancing markets, annual system operating costs continue to remain elevated, with rise in VRE (Refer to Figure 7).

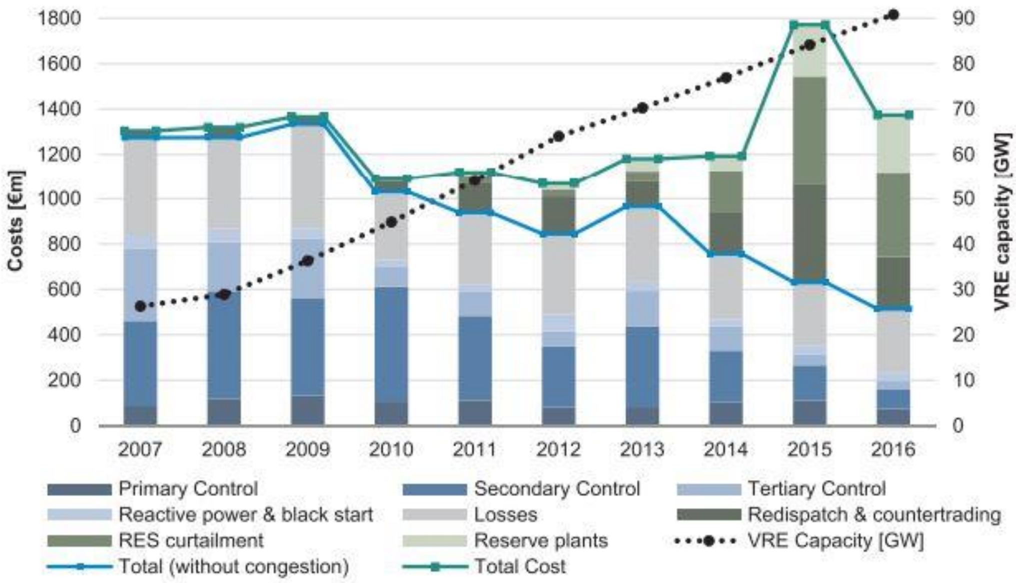

Figure 7: Total Balancing Costs for Germany

[16] Short-term integration costs of variable renewable energy: Wind curtailment and balancing in Britain and Germany; Michael Joos and Iain Staffell

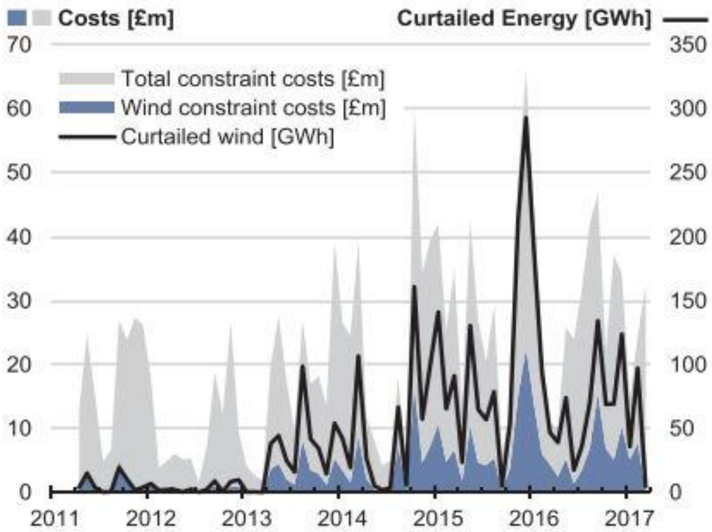

Figure 8: Cost of Compensating Wind Farms and Other Generators in Britain for Curtailment

Source: UK National Statistics

Instances of Forecasting Errors and Corresponding System Effects

A. Case from India

NREL modelled the implications for the country of India with the scenario of 100 GW of solar and 60 GW of wind is added to the system by 2022 (in line with the targets set out by the government)[17]. It has concluded that forecast errors will be larger in magnitude. Over forecasting errors (when actual RE generation is lower than forecasted generation) can lead to a system with low committed capacity from thermal units in real-time operations. On the other hand, under forecasting errors (when actual RE generation is greater than forecasted generation) can lead to coal generation will be required to be backed down to minimum generation levels.

In case of high over forecasting errors beyond stipulated reserve provisions, load demand may remain unserved. As per simulations, 4.8% of load (10.2 GW) will remain unserved on a day when forecasting error reaches 19.8 GW, or 10 GW over 9.8 GW of reserve provision. The study further points out that 100 GW solar and 60 GW of wind is achievable at 15-minute operational timescales with minimal RE curtailment. However, during highly constrained periods, reserve requirements may not be able to service load demand. Close to 1.4% of RE may be curtailed according to the study by 2022. Handling RE forecast errors and changes in net load (ramps) would require advanced RE forecasting techniques, otherwise, curtailments can reach as high as 12%.

B. Case from the US

A research conducted by NREL and VTT Technical Research Centre of Finland undertook a study[18] in 2016 to assess the RE penetration in different states and subsequent forecasting errors which are expected to emanate taking into account currently adopted forecasting systems in the country. With the country already having large penetration of RE in different parts of the country, the study deduces

[17]https://www.nrel.gov/docs/fy17osti/68530.pdf

[18] *The Combined Value of Wind and Solar Power Forecasting Improvements and Electricity Storage*

that forecast errors marginally reduce due to the geographic smoothing impacts of placing new capacity in locations that have different weather patterns.

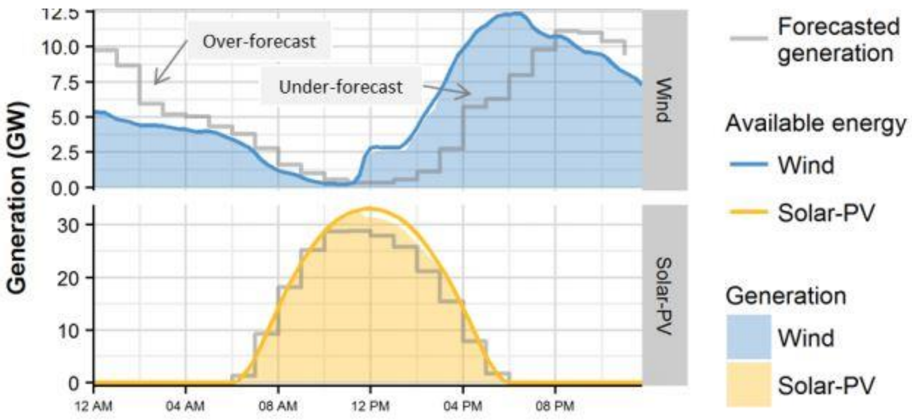

Figure 9: Under and Over Forecasting Modelled by NREL for 25th September, 2022 in India

Source: NREL

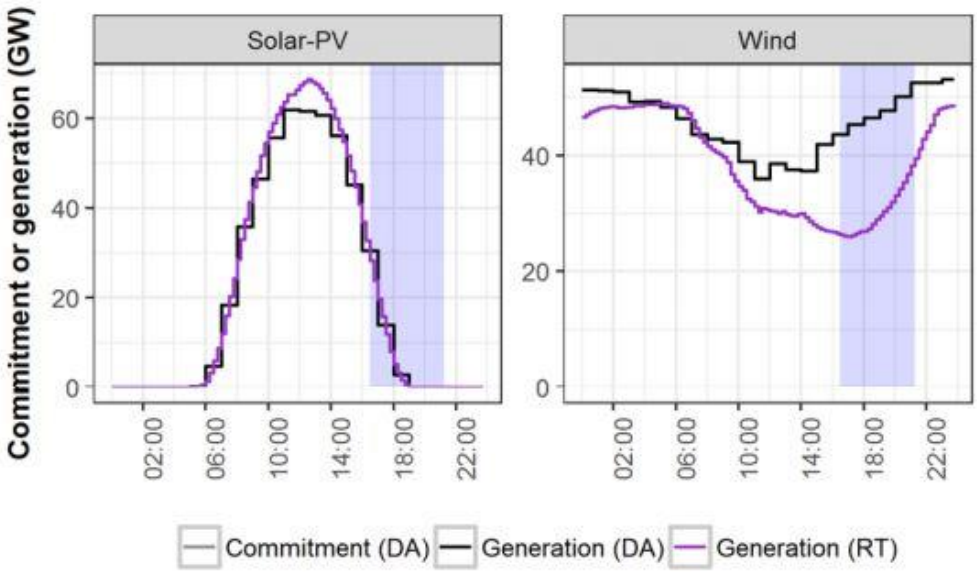

Figure 10: Wind and Solar Generation in both Day-Ahead (DA) and Real-Time (RT) Schedules

Note: Highlighted band is period of unserved energy

Source: NREL

Table 6: Forecasting Improvement for Different Renewable Energy Penetration Cases (Wind)

Normalized Wind Power Forecasting Error Values	11.6% RE Penetration	21.5% RE Penetration	31.5% RE Penetration	40.3% RE Penetration	56.4% RE Penetration
NMAE (%)	6.22	6.06	6.03	6.09	6.0
NRMSE (%)	8.02	7.79	7.75	7.84	7.83

Source: NREL-VTT Research study

Table 7: Forecasting Improvement for Different Renewable Energy Penetration Cases (Solar)

Normalized Solar Power Forecasting Error Values	11.6% RE Penetration	21.5% RE Penetration	31.5% RE Penetration	40.3% RE Penetration	56.4% RE Penetration
NMAE (%)	2.41	1.87	1.95	1.96	1.95
NRMSE (%)	6.10	4.75	4.53	4.48	4.41

Source: NREL-VTT Research study

Table 8: Forecasting Improvement for Different Renewable Energy Penetration Cases (Solar+Wind)

Normalized RE Forecasting Error Values	11.6% RE Penetration	21.5% RE Penetration	31.5% RE Penetration	40.3% RE Penetration	56.4% RE Penetration
NMAE (%)	3.49	3.15	2.87	2.99	2.49
NRMSE (%)	4.98	4.39	4.09	4.15	4.22

Source: NREL-VTT Research study

This shows that for developed markets, RE forecasting can improve with higher penetration of solar and wind power in the grid. However, it is observed in the study that without improvement in forecast methods, rise in RE penetration will lead to RE curtailment.

As observed in Figure 11, there is some amount of RE curtailment both in original forecasting and 0% forecasting scenarios. This curtailment is noticeably absent in the 40% improvement case because of the more efficient commitment, which allows for the utilization of this renewable energy.

Suboptimal commitment because of errors in the renewable energy forecasts, will have economic impacts. The aggregated impacts of these effects on production costs during the entire one-year simulation period for each combination of generation mix, forecasting improvement, and renewable penetration scenarios is shown as below. The study concludes that total operating cost savings can reach 1% while start-up and shut down cost savings can reach 10% in case of 40% improvement in forecasting techniques.

This can lead to large savings in overall power production costs, considering that the annual production and start-up and shutdown costs are significant in the CAISO and MISO systems.

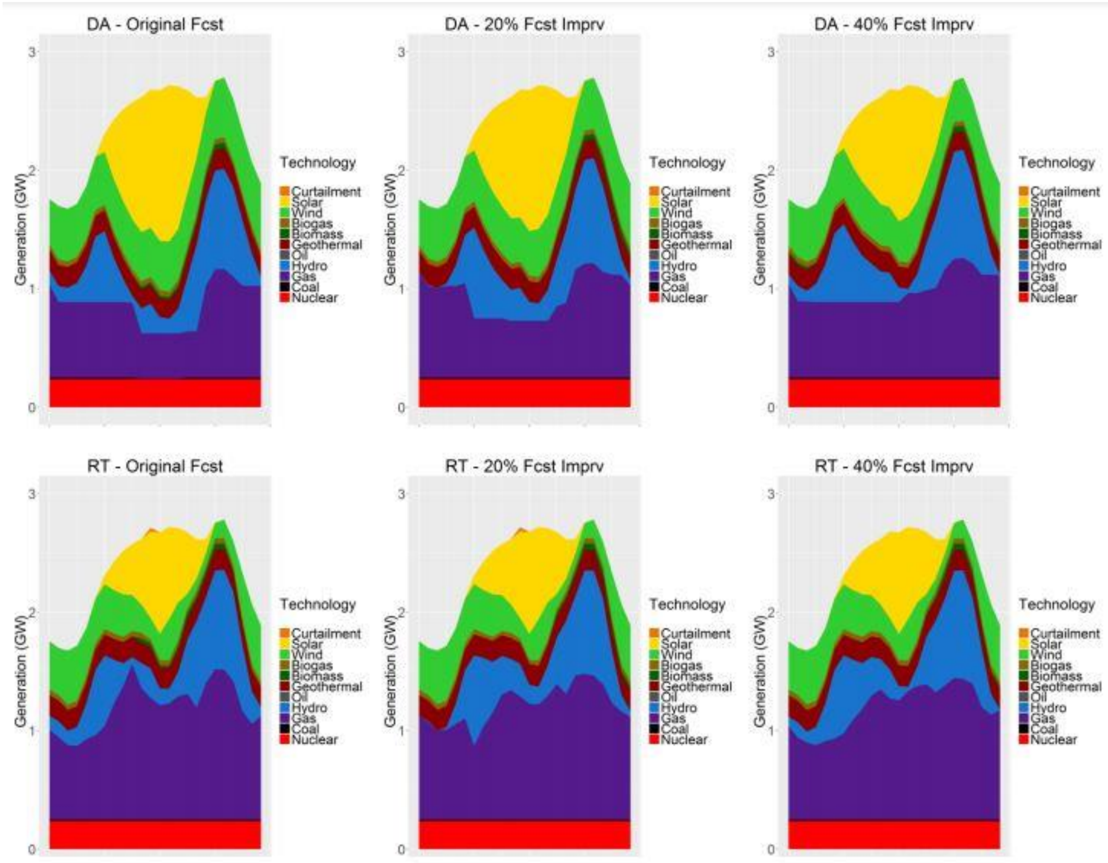

Figure 11: Impact of Forecast Improvements on the Generation Dispatch Stack

Note: DA: Day Ahead; RT: Real Time

Source: NREL-VTT Research study

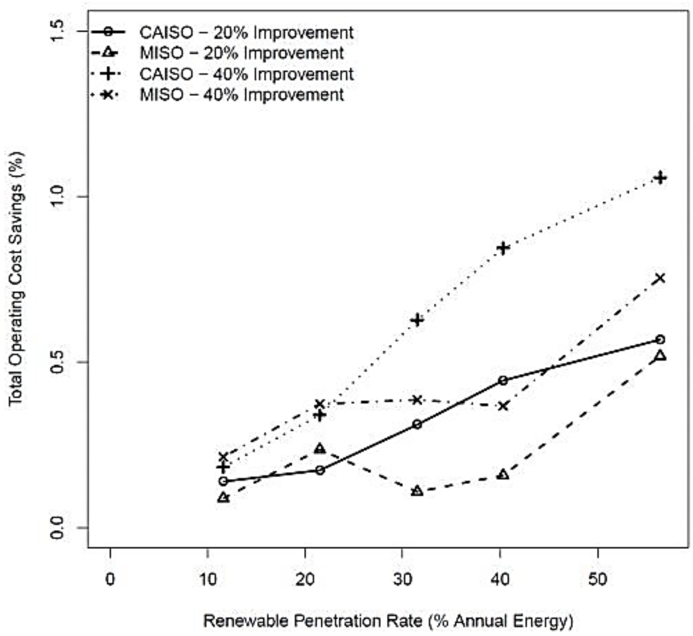

Figure 12: Total Generation Cost Savings (Percentage) from the 20% and 40% Forecasting Improvements

Source: NREL-VTT Research study

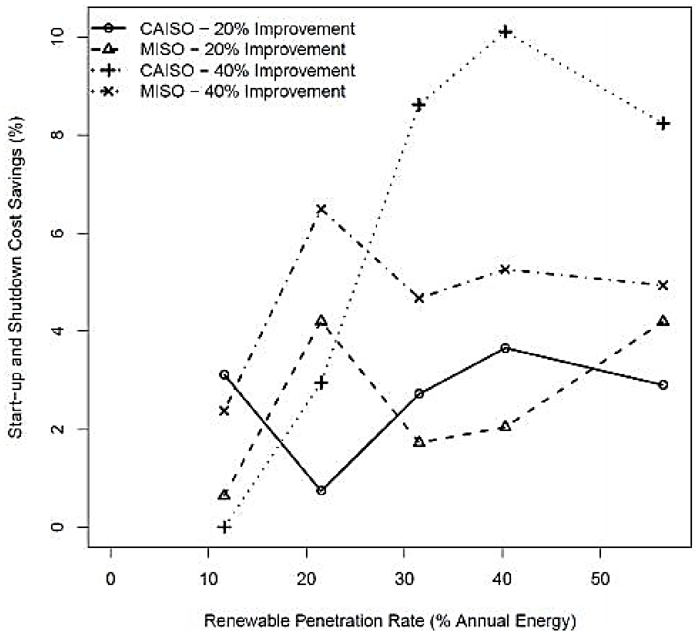

Figure13: Start-up and Shut down Cost Savings (Percentage) for each of the Forecast Improvement Scenarios and RE Penetration Rates

Source: NREL-VTT Research study

Table 9: Annual Production, Annual Start-up and Shutdown Costs in CAISO and MISO Systems

RE penetration (%)	CAISO		MISO	
	Annual Production Costs (M$)	Annual Start-Up and Shutdown Costs (M$)	Annual Production Costs (M$)	Annual Start-Up and Shutdown Costs (M$)
0.0	848	15.7	708	8.6
11.6	713	14.5	623	12.4
21.5	606	19.2	566	15.7
31.5	514	26.0	526	20.9
40.3	446	28.1	498	24.4
56.4	352	29.3	457	27.9

Source: NREL-VTT Research study

2.3.2 Impact on the Countries Owing to Adopted Wind and Solar techniques

Improved wind and solar forecasting has led to a rise in RE penetration in the power supply mix for the three countries. Power markets have deepened with a rise in short term power transactions. Grid operators and private entities have developed new forecast tools in each of the control centres which feed in wind and solar forecasts at half-hourly or quarter-hourly intervals, along with expected grid reliability levels. Furthermore, forecasts have helped to make necessary calculations for conventional generation capacity requirements and quantum of power trading.

A. Case from USA

A study, carried out by NREL, investigates the value of solar power forecasting improvements, both in terms of variable electricity generation costs and its impact on bulk power system operations. The different scenarios of solar power penetration and solar power forecasting have been compared on a cost basis, including generation, fuel expenditures, variable operation and maintenance (VO&M) costs, and start and shutdown costs. Moreover, operational impacts on conventional electricity generators are analysed including total electricity generation and hourly ramping. The study is performed by simulating the operation of the Independent System Operator – New England (ISO-NE) power system under a range of scenarios with varying solar power penetrations and solar power forecasting improvements. Data from 68 utility-scale solar power plants and 76 distributed solar power plants under ISO-NE has been used for analysis. The following was analysed:

Table 10 and Table 11 show that electricity generation from more expensive and faster generation sources [gas and oil Gas Turbine (GT) and Intercooler (IC) generators] decreased with solar power forecasting improvement.

Table 10: Impact of Solar Power Forecasting Improvement on Electricity Generation (Part 1)

Solar Penetration (%)	**4.5**				**9.0**			
Forecast Improvement (%)	**25**	**50**	**75**	**100**	**25**	**50**	**75**	**100**
Coal (% change)	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.3
Gas CC (% change)	0.0	0.2	0.1	0.1	0.1	0.1	0.2	0.3
Gas & Oil ST (% change)	-0.1	-1.4	-0.8	-0.8	0.6	1.2	0.5	0.0
Gas & Oil GT & IC (% change)	-0.8	-1.8	-1.9	-1.7	-4.5	-7.5	-8.6	-10.2

Note: CC: Combined Cycle, ST: Steam Turbine; IC: Intercooler; GT: Gas Turbine

Source: NREL

Table 11: Impact of Solar Power Forecasting Improvement on Electricity Generation (Part 2)

Solar Penetration (%)	**13.5**				**18.0**			
Forecast Improvement (%)	**25**	**50**	**75**	**100**	**25**	**50**	**75**	**100**
Coal (% change)	0.1	0.3	0.4	0.5	0.2	0.4	0.4	0.4
Gas CC (% change)	0.3	0.7	0.9	1.1	0.5	0.9	1.4	1.8
Gas & Oil ST (% change)	-1.3	-2.8	-3.9	-4.8	-1.9	-3.5	-5.3	-5.5

Solar Penetration (%)	13.5				18.0			
Forecast Improvement (%)	**25**	**50**	**75**	**100**	**25**	**50**	**75**	**100**
Gas & Oil GT & IC (% change)	-3.9	-8.8	-12.1	-13.7	-5.1	-10.5	-14.3	-17.5

Note: CC: Combined Cycle, ST: Steam Turbine; IC: Intercooler; GT: Gas Turbine Source: NREL

Table 12 shows that improvement in solar power forecasting in Day Ahead reduced the need the need to curtail solar power in real time.

Table 12: Impact of Solar Power Forecasting Improvement on Solar Power Curtailment

Impact (% change) Forecast Improvement (%)	Solar Penetration (%)		
	9.0	**13.5**	**18.0**
25	-2.3	-1.2	-1.5
50	-4.0	-2.3	-2.7
75	-5.2	-3.5	-3.5
100	-5.4	-4.2	-3.8

Source: NREL

Table 13 shows that normalized value per unit of solar power generation increased with solar power penetration. A 25% uniform solar power forecasting improvement reduced annual operational electricity generation costs by $3.92 M (equivalent to an average of $0.33 savings per MWh of solar power generation) and by $10.65 M (equivalent to an average of $0.50 savings per MWh of solar power generation) for 9% and 18% solar power penetration respectively.

Table 13: Cost Savings from Solar Power Forecasting Improvement per Unit of Solar Power Generation

Forecasting improvement cost savings ($/MWh) Forecast Improvement (%)	Solar Penetration (%)			
	4.5	**9.0**	**13.5**	**18.0**
25	0.11	0.33	0.39	0.50
50	0.29	0.62	0.77	0.95
75	0.30	0.74	1.03	1.25
100	0.32	0.82	1.13	1.42

Source: NREL

In conclusion, the results clearly show how forecasting improvements has a measurable impact on power system operations in the form of integration costs, while also improving on solar power curtailment levels.

B. Case from Italy

A study was carried out by National Centre for Atmospheric Research in 2014 to assess the economic impact of different wind forecasting systems for producers[19]. Two types of wind forecasts, probabilistic and deterministic, was carried out for 72 hours at a wind farm in Italy. While a deterministic forecast consists of a single value for each time in the future for the variable to be predicted, probabilistic forecasting informs on probabilities for potential future events. A significant probabilistic application is related to the trading of energy in day-ahead electricity markets. The paper concedes that while trading future wind energy production, using probabilistic wind power predictions can lead to higher benefits than those obtained by using deterministic forecasts alone. Probabilistic wind forecasts, based on the "analog ensemble" method for bidding wind energy during the day-ahead market can solve economic model equations and optimize revenue for the producer. In fact, the economic benefit of using a probabilistic approach for the day-ahead energy bidding can result in an increase of 23% of the annual income for a wind farm owner in the case of knowing "a priori" the future energy prices. The uncertainty on price forecasting partly reduces the economic benefit gained by using a probabilistic energy forecast system.

2.3.3 Policy Overview

Developed and mature renewable energy markets, such as the US, Germany, Spain and France, have put in place strong policies and institutional frameworks that enable sound electricity market designs, integrating renewable energy into grids and markets.

Market Design and Institutional Framework

A. Germany

The European electricity market was liberalised in 1996 with the European Parliament and the Council of the European Union deciding upon a directive with respect to development of European domestic electricity market. The directive required the Member States (or countries) to liberalize their electricity markets through unbundling of network operators, regulating the access to transmission and distribution networks and removing market access barriers.

In Germany, currently there are day-ahead and intraday spot markets based on merit order principle as well as an over-the-counter futures market and balancing power market. The distribution networks and the four control areas operated by Transmission System Operators (TSO) (Tennet, Amprion, 50Hertz, and TransnetBW) are regulated by a federal regulator, Bundesnetzagentur. The European Power Exchange (EPEX) contains a day-ahead market with tradable-hour contracts in Euro per MWh and a call-auction market with tradable quarter hour contracts in Euro per MWh. Additionally, continuous intraday trading facility is available to market participants until 45 minutes before delivery with tradable-hour or quarter-hour contracts. After the introduction of Renewable Energy Sources Act, 2000, which allowed guaranteed feed-in-tariffs to different technologies, renewable energy saw high investments.

B. USA

In the US, 16 states have deregulated their electricity markets till date by restructuring the vertically integrated electric utilities and, thereby, fostering competition among sellers. There are four Regional

[19] Comparison of the economic impact of different wind power forecast systems for producers

Transmission Organizations (RTO) and three Independent System Operators (ISO) that are both responsible to coordinate, monitor and control electricity transmission grids and move electricity over large interstate areas. All of these entities have established a power market. Moreover, there are three power markets in the Northwest, Southwest and Southeast regions. Electricity generated through wind or solar is mostly sold through power-purchase agreements (PPAs). In some markets of the US, grid congestion is taken into account to derive Locational Marginal Pricing (which is related to the generation marginal cost, the transmission congestion cost and the cost of losses).

In case of The Midcontinent Independent System Operator (MISO) [an RTO which provides electricity to consumers in 15 states], a day-ahead and real time energy market is used for power auctions. Furthermore, bilateral options and futures trading is active on the Intercontinental Exchange (ICE) market. Based on the different state legislated Renewable Portfolio Standards, put in place by states under MISO area, varying percentages of electrical energy is produced by renewable sources and further integrated in the grid.

C. Denmark

Denmark has developed and built up a well-functioning power system with high technical supply reliability. This has helped the Nordic nation to integrate large quantum of wind power (which constitutes more than 30% of the overall power generation) into the systems. Priority access is given to the grid, thereby providing an assurance to renewable energy power generators. The TSO or DSO, which are responsible for carrying out the necessary grid reinforcement, are encouraged and in many cases incentivised to finance the needed grid connection. The electricity market design in Denmark is similar to that of Germany. Renewable energy can be sold at energy markets at a market price and a price supplement. Wind energy power plants are further allowed to take part in the balancing power market.

The Nordic power exchange, owned by the Danish TSO and other Nordic TSOs, has two market places, Elspot and Elbas. Trade on Elspot is taken place based on the auction principle. The power exchange matches sales and purchase bids in calculating the spot market price one day-ahead of operation, taking into consideration the limitation of the capacity of interconnectors between the so-called bidding areas. On Elbas, player's trade imbalances occurred after gate closure at Elspot, to obtain balance. Additionally, financial trading and hedging takes place at the Nasdaq OMX Commodities platform.

The country has also set up strong interconnections with neighbouring countries (Norway, Sweden, and Germany) to ensure the functioning of a liberalised power market.

D. South Africa

South Africa has a vertically integrated utility called Eskom. It is responsible for more than 90% of the country's generation, and owns and operates the country's national transmission system. The country has been enabling private participation in the power space. South Africa Power Pool (SAPP) has been established in 1998, where surplus power from South Africa is traded with its neighbours, albeit mostly via bilateral contracts.

Forecasting of Wind and Solar

A. Germany

Renewable power generators have been accorded must-run status under the Renewable Energy Act 2000. The four TSOs are required to preferentially feed-in the generated RE power to the grid over electricity from conventional sources. This system has recently been modified to include a market premium system. Each of four TSOs are required to undertake forecasting services in their respective control areas. Over the years, the TSOs have built up their own expertise and are able to deploy their own post-processing schemes on the set of different power forecasts delivered by different providers. TSOs typically purchase several RE power forecasts and improve overall forecasting techniques through feedback and knowledge-sharing with the providers. Presently, each TSO has a forecasting system with access to the following data (a) Wind and solar forecast horizons of up to 7 days, (b) Temporal resolution of forecasts (15 min-1 hour), (c) Additional very short-term forecasts (up to 6 hours), (d) Updates on intra-day time scale, (e) Forecasts for ramps (time of occurrence, duration, magnitude, ramp rate), and (f) Information on forecast uncertainty (resulting from probabilistic forecasts). Typically, all RE forecast systems provide regional forecasting, although they are capable of delivering forecasts at any spatial scale down to a single RE generation plant.

B. USA

In the US, market participants have to deliver power schedules in a five-minute resolution. For RE schedules, different TSOs use separate mechanisms of forecasting and use the mechanisms differently for system and market operations. In the MISO market, market operations for solar and wind are done in an automated procedure. This requires day-ahead forecasts by market participants. The participants have to submit real-time bids 30 minutes before delivery. MISO also uses short-term forecasts in a five-minute resolution to dispatch power systems. Furthermore, MISO defines the maximum capacity for dispatchable intermittent resources (such as solar and wind) to automatically dispatch their generation based on offer prices and system conditions. MISO also maintains an outage and availability information for RE plants. By integrating the accurate outage and re-dispatch information, forecast accuracy is highly increased. The TSOs also have to forecast production from distributed PV installations. With utilities allowing net metering, surplus or deficit scenario of feed-in from rooftop PV installations and load profile change of households and businesses are undertaken.

Table 14: Overview of Wind Power Forecasting In U.S Markets

MISO	NYISO	PJM	ERCOT	CAISO
(a) DA and intra-day RAC (b) Transmission security and outage coordination (c) Transmission security and peak load analysis	(a) DA and intra-day RAC (b) Transmission security and outage coordination (c) Transmission security and peak load analysis	(a) DA transmission security and reserve adequacy assessments (b) Developing automated procedures (c) Specific ramp forecast	(a) 80% exceedance forecast used for DA planning (b) Fully integrated in new nodal design (c) Developing ramp forecast	a) Used to calculate energy schedule in RT market b) Advisory role in DA market

MISO	NYISO	PJM	ERCOT	CAISO
(d) Indication of ramps	(d) Indication of ramps			

Source: ISO documents

C. Denmark

The country has created an ecosystem for utilising strong RE forecasting systems. In fact, the country has developed several wind power forecasting systems. An example of a commercially successful statistical system is the Wind Power Prediction Tool (WPPT) that was developed by the Technical University of Denmark. It is now being operated and has been further enhanced by the Danish company, ENFOR. The model takes a constant data flow of NWP and production data which is further used to continuously calibrate the system with artificial intelligence methods.

The major reason for the development of wind power forecasting techniques is a strong policy push as well good private participation. The need for accurate forecasts is also driven by the possibility of wind power plants to take part in the balancing power market. The system operation is done day-to-day, hour-to-hour and minute-to-minute by the Danish TSO to ensure successful integration of wind power into the grid. The Danish TSO has developed a forecast and management system with enhanced real-time monitoring of the grid, including real-time estimates of the wind power fed into it. To receive inputs into the system, the Danish TSO requires all plants greater than 10 MW of capacity to provide production data every five minutes. Additionally, the forecasts, which may contain prognosis errors, are refreshed. The prognoses are updated every six hours owing to new weather forecasts, and as the hour of operation approaches, the prognoses are also updated with real-time information. This way, the system operation has good knowledge of possible regulating power needs (originating from the wind power uncertainty). The Elbas platform on the exchange allows for trading of imbalance power while system operators prepare to incorporate differences between forecast schedules and dispatch requirements.

D. South Africa

South Africa is the largest producer of electricity in the African continent. The system operator Eskom uses power forecasts to plan schedules for conventional generation. RE power plants, with installed capacity above 1 MW, need to submit week-ahead and hourly production forecasts to the system operator. With Eskom being the only buyer of power, dispatching and curtailing is done based on economic parameters, taking into consideration technical constraints. Wind plants have to provide wind speeds and wind direction while solar plants have to provide solar radiation information, with updates every minute. Eskom, in turn, sets up power curves for every generator, and calculates confidence indicators for the delivered power forecasts. However, there is no incentive for accurate forecasts and no imbalance costs need to be paid.

2.3.4 Conclusion

After assessment of the current best practices from countries with different regulatory frameworks and market designs, it can be observed that:

(a) Reliable real-time production data is important for short-term forecasting (which is very important for wind and solar forecasting)

(b) A good market of forecasting in the country helps spawn several forecast providers, who, with time and experience, are able to generate weather and RE supply output with a high degree of accuracy

(c) Strong book-keeping of meteorological data, previous plant-wise generation data, outages and curtailment information will help establish a reliable wind and solar forecasting system

(d) Evaluation of forecast accuracy and constant improvement on existing models by removal of systematic errors and biases will help improve the forecasting power of existing systems

(e) Regional RE forecasting leads to better results as compared with single plant forecasts on account of regional smoothing effects

3 ASSESSMENT FOR SAARC MEMBER STATES

This section will highlight the present status of RE and RE forecasting in each of the SAARC Member States and furthermore, conduct a GAP analysis.

3.1 Assessment of RE Scenario in SAARC Member States

This section discusses the present scenario of RE in each of the SAARC Member States as well as the 10-year outlook of potential capacity additions. Furthermore, the wind and solar maps for each SAARC Member State have been included in the Annexure (Chapter 7).

3.1.1 Afghanistan

Solar: The country has abundant solar energy. Blessed with an arid terrain and with more than 300 days per year counted as sunny, there is potential to generate ~222 GW of solar power as per the Ministry of Energy and Water (MEW). However, much of it remains under-exploited. Presently there is close to 20 MW of solar plants installed in the country? Some of the major solar plants include a 15 MW solar plant set up by Phelat Group and Zularistan Ltd, 2 MW Bamyam solar plant, and a 2 MW hybrid solar-wind project. Several off-grid solar plants providing power to schools, shops and communities constitute an additional ~12 MW of installed capacity.

Going forward, the country is expected to see improved traction in solar installations. Donor agencies such as Asian Development Bank (ADB) and United States Agency for International Development (USAID), along with multilateral financing agencies such as International Finance Corporation (IFC) and United Nations Development Programme (UNDP) are expediting solar projects in the country. The country is expected to see solar capacity additions of ~500 MW by 2030. Key upcoming projects include the 10 MW Kandahar-1 solar plant, 30 MW Kandahar-2 and three plants (15 MW each), Nangarhar solar plant (40 MW), Hisar-e-Shahi solar plant (40 MW), Farah solar plant (12 MW), and Khost solar plant (10 MW). Furthermore, micro solar plants and off-grid systems will see an additional ~50-100 MW of installations.

Wind: Afghanistan has close to 158 GW of wind power potential, with ~15.8 GW and 33.1 GW falling under superb and outstanding resource potential respectively, based on studies conducted by the MEW. Close to 12 GW of wind power is exploitable in the Herat province while ~10 GW is exploitable in the Nimruz province. However, the challenge lies in the evacuation of power through a strong transmission system. Herat has transmission links from the capital Kabul to both Iran and Turkmenistan, but is isolated from the rest of the country's transmission network. Nimruz, like Herat, is connected to Iran, and receives power at the 20 kV level. However, it has no transmission connections to other provinces. Farah does not have any connections either with the Afghanistan network or with Iran. Its power supply is limited to only a few isolated mini-grids. Given the isolation of the wind resources, substantial capital investment in transmission lines and substations is required to connect new wind farms even to local load centres. To supply wind power to the rest of the country, the currently isolated Herat network would need to be connected to the other parts of the existing transmission network, either by constructing a link to the northeast system in Farah province and/or by building a link to the southeast system at Kandahar. Private participation and lack of government oversight have hindered the development of wind power. Presently, there are there are no significant wind capacities in the country. As on 2019, only two wind power projects are operational: the 100kW wind plant in Punisher province and the 2 MW solar-wind hybrid (of which wind comprises of 300 kW).

Going forward, no large-scale wind power development is expected in the country. Based on analysis, ~100 MW of wind capacity additions are expected by 2030, led by three expected wind plants (Herat wind farm- 50 MW, Mazar wind plant – 25 MW, and Parwan wind plant- 25 MW).

3.1.2 Bangladesh

Solar: The solar sector in the country is still very nascent. This is primarily due to the fact that abundant non-agricultural land required for large solar installations is limited. The present installed solar capacity is ~400 MW (on-grid solar: 39 MW, off-grid solar: 355 MW). On-grid solar is generated from the current four operational plants (Kaptai- 7.4 MW, Panchagarh- 8 MW, TeknafUpazilla- 20 MW and SarishabariUpazilla- 3 MW). The country has additionally set up close to four million off-grid solar systems, comprising 100 to 5000 W systems, which have helped the country reach ~70% grid coverage in rural areas. As per Bangladesh Power Development Board (BPDB), close to 12% of the country's population has been living on off-grid systems.

Going forward, the country is not very keen to set up utility-scale solar installations at a rapid pace. As per Sustainable and Renewable Energy Development Authority (SREDA), ~400 MW of on-grid solar plants are under implementation while an additional 1 GW is at the planning stage. Bangladesh Renewable Energy Department intends to push solar adoption among garments and textile units, which comprise a large portion of the country's industry mix. Furthermore, it is exploring installation of floating solar power systems on large-scale water bodies in the country. As per analysis, ~1 GW of on-grid solar installations are expected to come up in the country by 2030.

Wind: Wind projects have not been able to take off in Bangladesh. In 2013, the government had intended to set up three wind projects, with a cumulative capacity of 260 MW. Among that, a 100 MW wind plant in Anwara area of Chittagong has been stalled while the other projects have been undergoing inordinate delays. Furthermore, scepticism among project developers (with wind being a novel technology in the gas-based power mix) has led to delays in project execution. Presently, there are ~0.9 MW of on-grid and 2 MW of off-grid wind projects in the country.

According to Bangladesh Power Development Board (BPDB), the potential of wind energy is limited to coastal areas. This is expected to hinder large-scale wind development in the country. Furthermore, lack of a reliable grid (to handle wind power intermittencies) is expected to deter adoption. Presently, ~ 2 MW of wind plants are in the implementation stage while an additional ~70 MW are in the planning stage. Small wind projects are expected to come up in the Kutubdia Island and Cox's Bazaar. As per analysis, ~100-150 MW of wind projects are expected to come up in the country by 2030.

3.1.3 Bhutan

Solar: Owing to its mountainous terrain and harsh landscape, solar and wind development in the country has been very less. However, despite its terrain challenges, the country enjoys good solar resources in several regions. The Department of Renewable Energy (DRE) and Ministry of Economic Affairs (MOEA) study estimates theoretical solar potential at 6 terawatts (TW) and restricted technical potential at 12 GW. Presently, there are ~1 MW of solar power installations in the country; however, the majority of them are off-grid systems. Solar housing systems and micro-grids have been deployed in remote areas to improve energy access. There are no existing grid-connected, utility-scale solar projects presently.

Based on Alternate Renewable Energy Policy (AREP), the solar target for the country is 5 MW in 2025. Although this is achievable, external funding and technology adoption will be key. As per analysis, on-grid solar installations are expected to reach ~10 MW by 2030, majorly through deployment of small-scale PV plants.

Wind: The country's wind cycle is heavily influenced by the seasonal monsoon, which means that wind speeds are high from November to April and low in the remaining months. This coincides with periods when hydro resources (the largest contributor of power generation in the country) are short, thereby offering an opportunity to diversify the power mix during low-hydro power seasons. However, most of the high wind-generating areas are located at high altitudes which are inaccessible and cumbersome for turbine installations. This limits potential wind deployments to ~760 MW with the northern dzongkhag (district) of Wangdue accounting for close to 19% of this potential, followed by the southern dzongkhags of Chukka (12%) and Dagana (10%). Presently, ~0.6 MW of wind capacities are operational in the country. Based on AREP targets, wind capacities are expected to reach 5 MW. However, owing to lack of on-ground implementation, it would be difficult to achieve. Based on analysis, the country's wind capacities will reach ~5 MW only by 2030-end.

3.1.4 India

Solar: India has an installed solar capacity of ~34.6 GW as of March 2020. Capacity additions in year ending March 2020 fell by 1.3% to 6,447 MW, from 6,529 MW solar capacity added in 2019. This was led by lower solar capacity addition in the second half of 2020, ~9% lower than compared with the second half of 2019. The states of Rajasthan, Tamil Nadu and Karnataka witnessed the highest capacity additions in 2020, with Rajasthan alone adding ~1.9 GW and the other two adding ~1.3 GW and ~1.2 GW respectively. In 2019, the state of Karnataka had seen the highest capacity additions at ~1.2 GW, followed by Rajasthan and Andhra Pradesh at 0.9 GW each. With tariffs falling to 3.14 cents[20] per kWh owing to a steep decline in module prices, economies of scale benefits and aggressive bidding by developers, the country has been seeing a boom in solar power development. Capacity additions of ~6.5 GW solar projects are presently under construction from different state policies while an additional ~5.8 GW is in tendering phase.

As per analysis, solar capacity additions are expected to reach ~56-58 GW over 2021-25 and ~95-105 GW over the next five years (2026-30), taking total solar installations in the country to ~185-195 GW in 2030.

Wind: As of March2020, the total wind capacities in the country stood at 37.7 GW. Wind additions picked up to ~2 GW in 2020 from 1.6 GW and 1.8 GW in 2019 and 2018 respectively. The improvement stems from several delayed projects getting commissioned in the year. Capacity additions had fallen 11% on year in 2019, with additions at 1.6 GW compared with 1.8 GW in the previous year. Capacity additions have been plummeting since 2018 on account of multiple factors, majorly due to the unplanned phasing out of feed in tariff regime by government and implementation of the competitive bidding of mechanism. The sector continues to adjust to the significantly lower tariffs under competitive bidding as well as land availability and grid connectivity concerns, where developers are facing issues from delayed/congested infrastructure.

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[20]*1 USD = 75.13 INR (As on 13.07.2020); 1 USD= 100 cents*

Capacity additions of 14-16 GW are expected over the next five years (2021-25) entailing investments of ~Rs 1 trillion. However, the change in the bidding mechanism has caused the entire industry to slow down owing to a significant fall in tariffs, where both bid response and profitability for original equipment manufacturer (OEMs) has dropped. Overall, cumulative wind capacities are expected to reach ~53 GW in 2025 and ~80 GW in 2030.

3.1.5 Maldives

Solar: Maldives has a miniscule penetration of renewables owing to its geographic isolation, lack of technology adoption and lack of land mass (for on-shore deployment). The country is an archipelago of more than 1,000 islands, most of them being sparsely populated or uninhabited. This lack of interconnection facilities makes holistic RE development increasingly difficult. Several studies are under way to assess the potential benefits of interconnection among islands in the Greater Male region (the most prosperous and populated area of the nation). However, initial results show connected, large-scale RE development is costly and uncompetitive. Presently, the country is adopting decentralized generation through RE means (majorly rooftop solar) to reduce dependence on diesel, which is imported and costly. Several resorts on islands with a major tourist influx have set up rooftop solar installations to cater to daytime peak load. The government has also approved feed-in-tariff and net metering regulations to promote private renewable energy. However, the segment is yet to take off in a large way due to weak grid position and lack of power access. Some programme such as Project for Clean Energy Promotion in Male and Preparing Outer Islands for Sustainable Energy Development (POISED) are being developed in the country, with the help of donor/ multilateral funding. For example, the POISED project is one of the largest energy sector interventions in the Maldives and intends to set up 21 MW of solar power plants as well as battery-powered systems in 160 inhabited islands. Presently ~7.5 MW of solar plants have been deployed under the scheme. Based on estimates, ~16 MW of solar PV projects are operational in the country. However, a large majority of them are decentralised and for private consumption. Going forward, ~50 MW of on-grid solar capacities are expected to get operational by 2030.

Wind: There has been no wind power development in the country. This is because wind turbines are more difficult to deploy and maintain as compared with solar PV. The government does not have any ongoing or upcoming wind power projects. Going forward, no significant wind project deployment is expected owing to lack of resources and high-cost implications. Some resorts, government schools and private buildings have been implementing very small scale, wind turbine for their own consumption. Uptake of private consumption through deployment of wind projects in private premises is expected; however, no large-scale wind power development is anticipated.

3.1.6 Nepal

Solar: Solar penetration in the country is limited majorly to rooftop solar installations in far-flung villages, where grid connectivity is weak or non-existent. The government has been subsidising solar home systems to improve uptake. As per the subsidy policy introduced in 2012 and amended in 2016, the federal government provides up to 65% subsidy for solar PV systems in public institutions of rural areas and 60% subsidy for solar PV systems for drinking water and irrigation systems. It has increased rural off-grid solar generation; however, large solar PV plant development has been elusive. As of 2020, there are only four on-grid solar plants operational in the country with a cumulative capacity of 1.78 MW. The country’s first large-scale (>10 MW) solar plant (Debighat solar plant) has recently been partially operational (15 MW of 25 MW) from April 2020, while the remaining 10 MW is expected to generate power from 2021. Additionally, ~30 MW of solar PV plants are in different stages of construction and expected to go live from year 2024-25. Lack of technical expertise, public funds and weak domestic power market are expected to deter large-scale solar installations going forward. As per analysis, the country is expected to reach ~80-100 MW of on-grid solar installations by 2030.

Wind: With Nepal being a mountainous country, lying along the middle part of a ~2,500 km-long Himalayan range, commercially viable wind potential is estimated to be only ~450 MW. Furthermore, the harsh topography and climactic conditions make wind installations difficult, and in most cases, unviable. As per Rural Integrated Development Service (RIDS), Nepal, based on data gathered by meteorologists, wind availability is majorly restricted to ~5-6 hours in a day during the non-winter months (some seven months). This restricts wind generation output, making wind projects unviable. In some villages, households are connected to small wind turbines. Additionally, the country is also experimenting with wind-solar hybrid solutions in some villages to improve power generation. However, large grid-connected wind installations are non-existent. No on-grid wind projects have been announced yet. However, going forward, with market maturity and technology improvement, the country may see some wind project development, reaching ~20-30 MW by 2030.

3.1.7 Pakistan

Solar: Pakistan has strong solar potential, especially in the areas of Sindh, Baluchistan and southern parts of Punjab. The country has ~2 GW solar installations as on March-2020. Some of the major solar projects which are operational include Quaid-e-Azam Solar 100 MW plant, Apollo Solar 100 MW plant and Best Green Energy 100 MW plant. The country's Alternate Energy Development Board (AEDB) has started a "solar power electricity programme" to electrify rural areas which do not have access to grid power. Under this scheme, close to 3,000 solar housing solutions have been installed in Sindh. National Electric Power Regulatory Authority (NEPRA), the county's power regulator, has also declared net metering policy and tariff regulations in 2015 to incentivise customers using solar PV.

Based on 'Indicative Generation Capacity Expansion Plan (IGCEP) 2047', prepared by NTDC, the country has prepared a power generation mix forecast. The share of solar in the Pakistan's power supply mix has been pegged at 12.79 GW by 2030 in a base case scenario and at 11.3 GW by 2030 in a pessimistic scenario (no policy support).

Although policy targets aim to increase solar adoption manifold over the next 10 years, implementation will be key. The country is yet to recognize RE as mainstream power technology. Solar PV technologies continue to be costly owing to lack of technology adoption and private participation. China and multilateral funding agencies like Japan International Cooperation Agency (JICA) and the World Bank have been providing technical assistance to improve solar PV uptake.

As per analysis, the cumulate utility-scale solar PV installations are expected to reach ~4-4.5 GW by 2030.

Wind: Pakistan has good wind potential. Based on estimates, ~346 GW of wind energy potential lies in the country, especially in the Sindh wind corridor which has abundant sources of wind up to 50 GW electricity generation potential. Under the study titled 'Wind Power Potential Survey of Coastal Areas of Pakistan' conducted in 2013, the Gharo-Jhimpir Wind Corridor was identified as one of the most lucrative sites for wind plants in the country, with a gross wind power potential of 43 GW. The government of Sindh intends to set up wind plants in the province by providing financial as well as non-financial incentives to wind developers.

Presently, ~1.5 GW of wind plants are operational in the country. Some of the major plants include Jhimpir wind plant (50 MW), Foundation Energy I and II (100 MW), Three Gorges First wind farm (50 MW), Sapphire wind plant (52.8 MW), and Artistic Energy wind plant (49.3 MW). Furthermore, in 2019, the country has signed deals with 11 wind Independent Power Producers (IPPs) to develop 560 MW of new wind power, all of which will be installed in the Jhimpir wind corridor. Cumulatively, ~610 MW of wind projects are under construction, majorly in the Gharo-Keti Bandar wind corridor (part of Gharo-Jhimpir wind corridor) while an additional 35 projects, with a cumulative capacity of 2.7 GW, is under development.

Based on the NTDC's IGCEP 2047 report, 10.33 GW of wind power is expected to be developed by 2030 in a base case scenario and 3.5 GW by 2030 in a pessimistic scenario (no policy support). Considering federal policy targets, project pipelines as well as on-the-ground implementation challenges, ~4.5-5 GW of wind projects are likely to be operational by 2030.

3.1.8 Sri Lanka

Solar: Solar power is abundantly available in Sri Lanka, with the country lying in the equatorial belt. It is estimated by the country that the technical potential for use of solar energy for electricity generation is ~6,000 MW. The country has good wind energy resources that are concentrated in the north-western coastal area and in the central highlands. However, implementation remains low. As per the Long-Term Generation Expansion Plan (LTGEP) 2020-2039, out of an installed power supply capacity base of 4,048 MW as on 2019-end, Sri Lanka has ~51.36 MW of utility-scale solar plant capacities. The installed base comes from eight small-scale solar plants. Additionally, ~107 MW of small-scale rooftop projects are presently operational, taking cumulative grid-connected solar PV installations to ~160 MW. Under the net metering scheme introduced by the government in 2010, ~14,700 rooftop solar installations have been completed, giving an impetus to the distributed generation segment. In the second phase of the accelerated solar development programme, the Ceylon Electricity Board (CEB) has begun development of ~150 MW of rooftop solar projects, due for completion in the next 2-3 years. Large-scale solar development has been planned and Sri Lanka Sustainable Energy Authority (SLSEA) has been identifying resource locations at Trincomalee, Ampara, Monaragala, Hambantota, Kurunegala, and Anuradhapura areas. As per analysis, ~500 MW of utility-scale solar installations are expected in the country by 2030. Additionally, close to 1,200 MW of rooftop solar installations are expected during the same time, taking the cumulative installed solar base to ~1,900 MW.

Wind: Sri Lanka presently has an installed wind capacity of ~128.45 MW as on 2019-end. As per the wind resource map prepared by the country, Sri Lanka has a total wind potential of ~5,600 MW; however, realizable wind potential is only ~1,500-2,000 MW. Therefore, Sri Lanka is not a potentially significant market for wind energy. Several challenges hindering wind development in the country include (a) geographical distribution of power demand centres and wind resources, (b) unavailability of new and updated transmission network to absorb variable RE including wind, (c) lack of power plants to cater the intermittency (especially in drought seasons), and (d) lack of dynamic modelling / advanced forecasting tools and technical knowhow. Going forward, the government intends to undertake grid impact studies to understand the requirement of grid enhancements to strengthen transmission facilities in order to facilitate large-scale wind development. SLSEA has identified resource locations for large-scale wind power development in Mannar, Jaffna peninsula, Kokilai, and Puttalam areas. While the Mannar wind farm project (100 MW) is in development stage, Pooneryn Energy Park (250 MW) is under planning. However, timely implementation is key. As per analysis, wind capacities in the country will reach ~800 MW by 2030.

Table 15: Solar and Wind Capacities in SAARC Member States (Review and Outlook) (In MW)

Country	Present (CY2019/ FY2020)		CY2024/ FY2025		CY2030/ FY2031	
	Solar	Wind	Solar	Wind	Solar	Wind
Afghanistan	20	0.4	200	40	500	100
Bangladesh	39	0.9	250	50	1,000	100
Bhutan	0	0.6	2	2	10	5
India	34,627	37,694	90,000	53,000	190,000	80,000
Maldives	5	0	15	0	50	0
Nepal	1.78	0	35	5	80	20
Pakistan	2,000	1,500	3,000	2,500	4,000	4,500
Sri Lanka	160	129	900	250	1,900	800

Source: RE documents of SAARC Member States

3.2 Status of Wind and Solar Forecasting Techniques in SAARC Member States

This section and its sub-sections aim to establish the current status in each of the SAARC Member States with regards to their progress in wind and solar forecasting. The upstream requirements of data collection frameworks for both static and dynamic data along with the status of the NWP is also assessed to form a comprehensive picture. Some of the insights are derived from primary research activities carried out in each of the SAARC Member State.

3.2.1 Afghanistan

The power sector in Afghanistan is regulated by the MEW and operated by the Da Afghanistan Breshna Sherkat (DABS) across the entire country divided. It is into 34 provinces which are governed by four different networks, i.e., North East Power System (NEPS), South East Power System (SEPS), Herat System, and the Turkmenistan System along with other smaller independent networks. Even within the four networks, the systems operate in an islanded manner on the basis of the source of generated and imported power. This has led to asynchronous systems operating in Afghanistan which makes integration of renewables an even bigger challenge than it would be for a larger interconnected system.

Power generation in Afghanistan is largely dependent on hydro power and sourcing from import lines connected to neighbouring countries. The current installed wind and solar power capacities stand at 0.4 MW and 20 MW, respectively, which is a small percentage of the total generation capacity in Afghanistan of about 340 MW in total.

Meteorology

The Afghanistan Meteorological Department (AMD) was established in 1955 and operates under the Afghanistan Civil Aviation Authority (ACAA). The department is currently providing weather forecasts up to 3 days ahead. AMD currently utilises the METCAP+ software developed by the Turkish State Meteorological Service (TSMS) to collate weather data and publish forecasts and visualisations. AMD does not have the resources to carry out weather forecasting for the very short term (nowcasting). However, seasonal temperature and precipitation forecasts (spanning over the next three months) disseminated through their portal are derived from GEOS5 (Goddard Earth Observation System Version 5) and Can-CM4 (Canadian Coupled Climate Model Version 4). The extent of utilisation of global forecast products and regional weather forecast generated using NWP by AMD stands at ~20% and 40%, respectively, as per World Bank estimates. These are based on a study which estimates the current capacity of the AMD in providing hydro-meteorology services[21].

One of the crucial ingredients for the production of high-quality weather forecasts with appropriate lead time is the accessibility/availability of real-time meteorological observations. The observation network used for relaying surface weather variables now rely on 28 synoptic stations but the observational infrastructure is mostly outdated and data recorded is unreliable. AMD is currently in the middle of improving its capacity with respect to its meteorological prowess with the support of the USAID-WMO EWS (United States Agency for International Development-World Meteorological Organization Early Warning System) project. With respect to the infrastructure associated with weather monitoring and observing systems (current capacity of ~30%), AMD is largely reliant on METAR (Meteorological Terminal Airport Report) data and satellite imagery.

AMD is currently undertaking upgradation in its communication infrastructure which would eventually provide them with access to a plethora of global NWP products (from ECMWF, the UK Met Office, and the Global Forecasting System or GFS of the US). However, current forecast requirements are only met within the short-range forecast span using weather data accessed through METCAP+, which is inclusive of the freely available GFS global model output at a spatial resolution of ~22 km. AMD has no country-specific weather forecasting platform in place for the renewable energy industry to readily take advantage of. Deployment of regional-scale limited area weather model (e.g., WRF) to dynamically downscaled global weather model output will lend its benefits to improved warning of natural hazards along with the generation of valuable weather inputs for the renewable energy industry. Moreover, accessibility to real-time weather observations (and its archival) is a critical prerequisite for ensuring the generation of accurate weather forecasts for decision making.

Wind and Solar Forecasting

The Afghanistan Power Sector Master Plan, most recently prepared in 2013, focuses on achieving a security of supply for the country. However, it does not delve much into the role of wind and solar

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[21]World Bank Group. 2018. Strengthening Hydromet and Early Warning Services in Afghanistan: A Road Map. World Bank, Washington, DC. © World Bank. https://openknowledge.worldbank.org/handle/10986/31059

power as grid-connected entities. The integration of solar and wind into the several asynchronous networks would not be a major area of attention for the country's power sector development in the current stages. This is because in the absence of other alternative sources of power or storage, wind and solar power do not provide the basis for a secure and stable power supply which is the immediate need for meeting an increasing demand in the country. However, wind and solar power generation are expected to increase to 100 MW and 500 MW, respectively, by 2031 which would represent a significant increase of intermittent solar and wind power in the generation mix. Such an increased penetration would require forecasting efforts to maximise the gains from these sources and also enhance investor confidence in establishing greater capacity. Given the asynchronous nature of grid operations in the country, the need for forecasting is even more pronounced. As the development of solar and wind power is in nascent stages in the country, forecasting finds no mention in the National Renewable Energy Policy of the country either.

3.2.2 Bangladesh

Bangladesh has currently installed wind and solar capacities of 0.9 MW and 39 MW, respectively, with limited short-term plans for increased capacity additions largely due to land use constraints. The growth in capacity of wind and solar is expected to reach 100 MW and 1000 MW, respectively, by 2030. This presents a requirement for increased wind and solar forecasting proficiency in the country.

The promotion and facilitation of renewable energy including wind and solar power falls under the ambit of the SREDA. The remaining power sector institutions in the country are constituted by an unbundled group of organizations comprising the Bangladesh Energy regulatory Commission (BERC), generation companies, the Power Grid Company of Bangladesh (PGCB) acting as the TSO and distribution companies.

Meteorology

The meteorological services are exclusively disseminated by the Bangladesh Meteorological Department (BMD) which actively maintains a network of surface/upper air observatories, radar/satellite stations and meteorological telecommunication system. It's headquartered in Dhaka with a couple of regional offices namely, the Storm Warning Centre (SWC) in Dhaka and the Meteorological & Geo-Physical Centre (M&GC) in Chittagong. The key roles fulfilled by BMD include near-real time monitoring of surface/upper air weather variables, preparation/analysis of weather charts, surveillance of extreme weather conditions using radar/satellite imagery (MTSAT, Himawari, METEOSAT, INSAT) along with prompt dissemination of forecast data in the form of warnings to the relevant stakeholders. The observational infrastructure comprises 42 surface observatories, 10 pilot balloon stations, three rawinsonde observatories, 12 agromet observatories, four radar stations (at Dhaka, Rangpur, Cox's Bazar, and Khepupara) and two operational high-gust anemometers.

Nowcasting (up to 24 hours) of precipitation and temperature along with forecasts spanning up to five days ahead are disseminated by the BMD. Extreme weather conditions associated with cyclones, kalbhaishakhi, squall, heat/cold wave, etc., are also included in the warnings issued by the BMD to the public. The BMD uses a range of weather forecast products to capture the future states associated with the evolution of the atmosphere. They include GFS model analysis from NOAA (National Oceanic Atmospheric Administration), limited area products derived from WRF (Weather Research and Forecasting) , GSM (Global Spectral Model) forecasts, ECMWF(European Centre for Medium Range Weather Forecast) forecasts, NCMRWF (National Centre for Medium Range Weather Forecast) forecasts from India, NHM forecasts, empirical/dynamical storm surge models, and T213 medium range forecasts, along with forecast products from HLAFS (Regional Forecast System developed by China). Extended range forecasts spanning 1-3 months are derived from Tokyo Climate Centre, Japanese Meteorological Agency for temperature and rainfall including their respective anomalies across the timespan of interest. The BMD also derives meteorological insights from the T213 medium-range weather forecasting tool which updates its forecasts twice a day.

The existence of an operational weather model configured at a regional scale along with accessibility to near real time observations capable of improving the weather forecast offers the BMD the opportunity to leverage its current weather capabilities/expertise to meet the meteorological demands of the renewable energy industry.

Wind and Solar Forecasting

Bangladesh has a wind and solar power potential of ~3,400 MW, assuming limited land use and not considering hybrid plants. This represents a small fraction of the power supply requirements of the country. As per studies undertaken by the International Energy Agency (IEA), injection of up to 10% power from the solar and wind power generated does not represent a major technical challenge as such a variation is similar in scale to what happens during unplanned power outages and load changes. As it stands, there is no existing regulatory mechanism for forecasting in Bangladesh and little to no efforts towards forecasting the wind and solar generation. The focus is still on increasing capacity additions which are at levels insignificant in terms of grid integration and do not require forecasting to be done at current levels.

3.2.3 Bhutan

Bhutan currently has an installed wind power capacity of 0.6 MW, estimated to expand to 5 MW by 2030, whereas its solar power capacity is expected to grow from scratch to 10 MW. This represents a small fraction of the ~1,600 MW hydropower generated, which is Bhutan’s major generation component and also qualifies as a renewable resource. However, there is an interest in alternatives to hedge against the low supply of hydropower generated during the nation’s dry winters and create a diversified electricity supply mix.

The electricity utilities in Bhutan come under two major entities - Druk Green Power Corporation Ltd (DGPC), responsible for power generation, and the Bhutan Power Corporation (BPC), which is responsible for transmission and distribution of electricity. Both utilities are state-owned. BPC operates generation plants below 5 MW capacity. BPC also retails electricity to customers in the country. The Bhutan Electricity Authority is the electricity regulator in the country.

Meteorology

The National Centre for Hydrology and Meteorology (NCHM), an autonomous agency since August 2016 under the jurisdiction of the Government of Bhutan, acts as the nodal point for the dissemination of weather services in the country. NCHM operates an observation station network comprising 20 agro-met weather stations (that measure rainfall, temperature, wind, sunshine duration, soil temperature and evaporation), 64 climatology stations (capable of measuring rainfall, temperature, humidity on a daily basis) and 80 operational automatic weather stations along with 1 upper air observation platform. The hydrology network maintained by NCHM consists of 15 principal stations and 9 secondary stations, whereas the Flood Warning Network comprises 15 hydrological stations.

NCHM also has access to weather products delivered by the Himawari-8 satellite operated by Japan Meteorological Agency.

NCHM has also developed in-house capabilities to downscale the global weather model output using the WRF model to generate forecasts with a horizon of 24-72 hours. The forecasts are updated four times daily. The in-house configured weather model output gets disseminated through their web portal. NCHM can also generate seasonal precipitation forecasts for the summer, monsoon (June to September) and winter seasons (December to February). The meteorological body maintains a reliable archive of historical meteorological data as well.

The current capabilities of NCHM do not allow the body to generate impact-based forecasts. Prompt monitoring of weather variables via observation network and satellite-derived data products along with weather forecasts generated in-house serves as the foundation for warnings associated with extreme weather events including thunderstorms, heavy rainfall, floods etc.

NCHM lacks the capability to generate medium range/extended range weather forecasts. The short-term weather forecast along with the operationalised observation station network could provide valuable weather inputs required to generate power forecasts up to three days ahead. However, extending the forecast timeline beyond the three-day limit still remains a challenge for NCHM owing to the absence of medium-range weather forecasting capabilities.

Wind and Solar Forecasting

Forecasting of wind and solar power in the nation is not crucial to the operation of the grid, due to miniscule RE generation. However, as understood during the primary consultations, forecasting practices are being carried out by the country. Static and dynamic data are carried out through standardized data collection frameworks and SCADA systems.

Furthermore, supported by the relatively-advanced NCHM, BPC forecasts wind and solar power to be generated and evacuates the same.

3.2.4 India

With an installed renewable energy capacity of 65 GW, comprising largely of solar and wind power, India is the most advanced among the SAARC nations in terms of wind and solar power forecasting.

Power System Operation Corporation (POSOCO) manages the grid whereas the Power Grid Corporation of India Ltd (PGCIL) is the central transmission utility owning all national grid transmission assets. The state grids are owned and managed under the same organisations.

Meteorology

The Indian Meteorological Department (IMD), established in 1875, operates under the Earth System Sciences Organization (ESSO) of the Ministry of Earth Sciences (MoES). Numerical weather prediction in India is carried out by both the IMD and the National Centre for Medium Range Weather Forecasting (NCMRWF). Both operate high performance computing systems (HPCS). NCMRWF, through a MoU with United Kingdom Meteorological Agency (UKMET), operates the NCUM global model, in which observational data is assimilated to provide forecasts for all weather variables, including the ones of interest to wind and solar power forecasting. IMD also deploys a high-resolution spectral model GFS T574 (a variant of Global Forecasting System) in its HPCS environment, along with its data assimilation system [adopted from National Centres for Environmental Prediction (NCEP), USA]. Additionally, the multi-resolution nested mesoscale model using WRF has also been operationalised by the IMD to run twice a day using spatial resolutions of 27 km, 9 km and 3 km. IMD regional centres (around 10 of them) have operationalised high resolution mesoscale models (WRF at 3 km resolution). Another key tool used by the IMD for generating weather forecast is the Multi-Model Ensemble (MME) derived using the output obtained from five NWP models namely - JMA T899, NCEP GFS, ECMWF T799, IMD GFS T574 and UKMO. This ensemble of models provides a comprehensive coverage of NWP in India.

The forecast span of weather data products issued by IMD were found to vary from short (1-3 days)/medium range (up to 3-7 days ahead) up to long range (> 1 month,) including extended range forecasts (15 days to about a month).

IMD is the nodal agency that disseminates NWP data to multiple organisations and agencies including POSOCO under the Ministry of Power.

Wind and Solar Forecasting

As the requirement for forecasting is set in regulations and mandated for all generators, forecasting of wind and solar power in India is carried out by multiple parties as forecast service providers (FSPs) have been engaged by generators or Qualified Coordination Agencies (QCAs). Additionally, some QCAs and generators generate forecasts themselves by developing capacity for forecasting in-house. As there are multiple parties involved in forecasting including international and domestic providers, a wide range of forecasting techniques are deployed in India. Hybrid models for forecasting wind and solar power are most commonly used in India. Generators and QCAs engage multiple FSPs to achieve higher accuracies, and hence, attract lower financial penalties. Penetration of advanced methods for solar forecasting such as sky imaging systems and satellite imaging is low in India owing to the high costs of implementation.

India has established Renewable Energy Management Centres (REMCs) in renewable energy resource-rich states in the country along with regional and national nodal agencies, totalling 11 centres under the Green Corridor Project of the Ministry of New and Renewable Energy. REMCs are wind and solar-focussed control centres at each of the dispatch centres and implement forecasting via an advanced artificial intelligence and optimisation enabled forecasting tool. Close to 55 million Euros (USD 62 million) was incurred to set up the REMCs.

In addition to the forecasting tool, the REMCs enable centralised real-time monitoring of all wind and solar generation stations and the weather conditions prevailing over their respective locations. In order to set up the REMCs, a standardised framework for collecting and storing all static and dynamic data related to wind and solar power generation stations across the relevant states has been created and implemented, and all wind and solar assets have been mapped extensively.

3.2.5 Maldives

The State Electricity Company Ltd (STELCO) is the sole fully integrated state-owned electricity utility in the Maldives responsible for generation, transmission and distribution.

The Maldives is expected to have an installed capacity of 50 MW of solar power by 2030 with 5 MW installed currently. No wind capacity has been installed or planned in future.

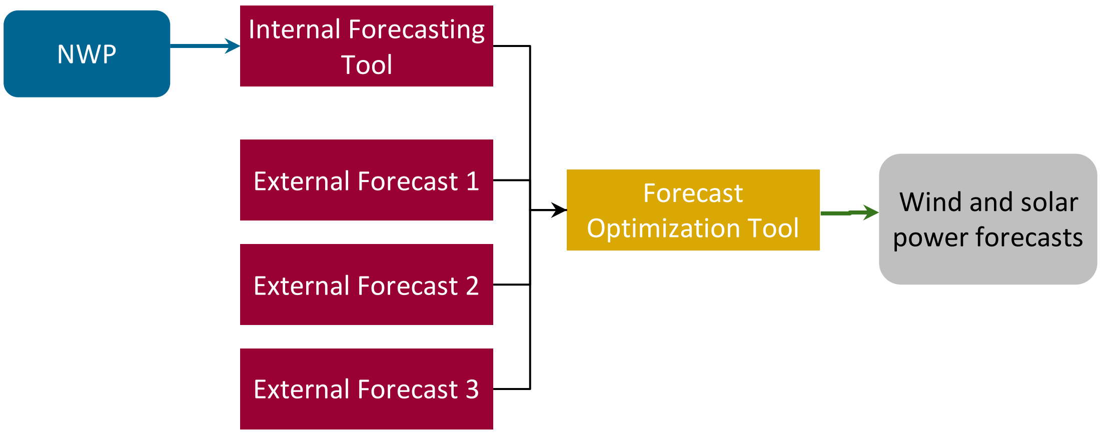

Figure 14: Tool Adopted in India for Wind and Solar Power Forecasting

Source: IMD

Meteorology

The observation network deployed by the Maldives Meteorological Service (MMS) established in 1942, currently comprises 36 operational automated weather stations, 3 tide gauge stations along with an upper air observation platform. MMS consists of five manned meteorological offices that span across the island chain. It also has access to meteorological data accessed via satellite imagery derived from FY-2E and FY-2G, relayed via the China Meteorological Administration (CMA) and cast using Satellite Weather Application Platform (SWAP). Additionally, MMS also has access to 3D imagery from the Indian satellite INSAT along with METEOSAT-8 satellite data products to generate additional meteorological insights in near-real time. Access to Doppler weather radar products spanning a radius of 270 km provides MMS with the capability to monitor weather adjacent to the island chain neighbourhood in order to issue warnings with appropriate lead-time.

MMS also relies on a range of weather forecast products issued by multiple agencies to provide insights into the future state of the meteorological variables. These products are derived from agencies including the Indian National Centre for Ocean Information Services (INCOIS), Regional Integrated Multi-Hazard Early Warning System for Africa and Asia (RIMES), European Centre for Medium Range Weather Forecast (ECMWF), Fleet Numerical Meteorology and Oceanography Centre (FNMOC) and Indian Meteorological Department (IMD). MMS has also ventured into an experimental deployment of the in-house weather model using the WRF framework configured at a spatial resolution of 27 km for the explicit purpose of generating mesoscale weather forecasts using a weather model architecture that is appropriately tuned to meet the needs of the country.

With its observational network and nascent NWP efforts, MMS currently directs most of the meteorological insights to cater to the needs of the public (e.g. issuing timely warnings pertaining to inclement weather) and the aviation sector. The meteorological body uses fax services, Short Message Service (SMS) and social media to disseminate weather alerts. However, MMS still lacks the capability to generate impact-based forecasts.

Owing to the lack of a mature and reliable weather forecasting operational platform to generate short/medium range weather forecasts, the Maldives is currently not in a position to provide the meteorological prerequisites demanded by the renewable energy generation forecasting services associated with the wind and solar energy sectors.

Wind and Solar Forecasting

The islands of the Maldives rely heavily on imported fuel for electricity generation and the rising prices of fuel provide incentive for growth of renewable power in the country. However, distributed and direct use of renewable energy technologies such as rooftop solar and solar water heating, etc., do not require forecasting to be done for operational or planning purposes. The requirement for forecasting in the country is very limited. Variability in supply due to growth in penetration of solar power generation in the country is most likely to be managed through easily controllable fuel generators and supported by battery storage.

Grid-connected solar generators must file applications through standardised framework, abiding by the Manual for Photovoltaic Grid Connection Application, which has limited provisions for static and dynamic data collection. The lack of frameworks to monitor and maintain records of grid-connected solar generation plants coupled with weak support from the meteorological department for forecasting wind and solar power underscores the early stage of development of forecasting in the Maldives.

3.2.6 Nepal

Nepal has a very limited penetration of wind and solar power with current capacities at 0 MW and 1.78 MW, respectively. This is because of the difficult geography of the country from the perspective of developing wind and solar power. At these levels and future targets of 20 MW and 80 MW for wind and solar power, the need for forecasting such power generation is minimal or negligible.

Given the relatively small control area for the electric grid in Nepal, the bodies governing the power sector are unified into a single entity. The Nepal Electricity Authority (NEA) is the vertically integrated utility in Nepal with control over generation, transmission and distribution of electricity. IPPs may connect with the grid and supply power to NEA directly through bilateral contracts.

Meteorology

The dissemination of weather forecasts for Nepal is entirely managed by the Meteorological Forecasting Division (MFD), Department of Hydrology and Meteorology (DHM), Government of Nepal. The observation network for meteorological variables spans across 282 locations within the country. They include 1 automated weather station, 9 synoptic stations, 21 agro-met stations and 169 stations that measure precipitation and 76 climatology stations. It also actively maintains around 50 hydrological stations that monitor moisture variables in near-real time. Apart from the aforementioned channels, MFD has access to the Himawari satellite imagery (provided by Japanese Meteorological Agency), which provides near-real time synoptic view of the country along with its neighbourhood of interest. The institution also archives the observational data, which spans all the way back to 2010.

The numerical weather modelling efforts of MFD are centred on the deployment of the mesoscale model Weather Research and Forecasting Environmental Modelling System (WRF-EMS). The configuration and deployment of the mesoscale model was implemented with the support of Finnish Meteorological Institute's (FMI) Meteorological Forecasting Division (MFD) at the Department of Hydrology and Meteorology in July 2015. The model generates forecasts at both 4 km and 12 km with a temporal resolution of an hour. The forecasts get revised four times in a day using initial/boundary conditions derived from the GFS global weather model. The forecast span of interest ranges up to three-and-a-half days ahead. Key meteorological variables including precipitation, temperature, wind and wind gust derived from a 4 km forecast are disseminated through the division's web portal. The numerical weather model output also provides key insights and inputs to improve the flood forecasting platform and warnings pertaining to floods. The Flood Forecasting Section (FFS), Hydrology Division, Department of Hydrology and Meteorology, Ministry of Energy, Water Resources and Irrigation, Government of Nepal, remains the fundamental authority for the dissemination of forecasts pertaining to floods and the warnings associated with the same along with the near-real time monitoring of river water levels/rainfall received through its web portal.

The weather forecasting service prevalent in Nepal is mature enough to provide key meteorological inputs (derived from its in-house weather model) to the renewable energy industry. The availability of near-real time observations provides an additional advantage of assessing the forecast quality along with the potential to improve forecast accuracies.

Wind and Solar Forecasting

As per responses received from stakeholders, wind and solar power forecasting is at a very nascent stage in the country with static data collected for grid-connected systems at the time of surveys and licencing. Dynamic data collection is dependent on availability of communication networks for off-grid systems and SCADA established for grid connected systems. Off-grid systems do not require forecasting as there is no risk to network stability.

With the country lacking utility-scale RE projects and limited to off-grid and residential systems, the need for forecasting and consequently, the status of forecasting in the country is lacking.

3.2.7 Pakistan

With installed solar and wind capacities of approximately 2 and 1.5 GW, respectively, Pakistan does not rely heavily on these renewable sources of energy for power generation. As this represents a less than 3% share of the total power generated, the need for forecasting the wind and solar capacity for efficient grid operations is not immediately apparent. As per primary surveys conducted with the stakeholders in the country, the generators themselves forecast the power outputs and share them with the relevant organizations. This represents a non-formal use for forecasts and is limited in scope. The grid operators manage RE integration through an enforcement mechanism that applies to generators as well as spinning reserve capacity and the demand side. However, with rising capacities and conservative estimates pegging the net installed capacity at 8-9 GW, the need for forecasting will only increase.

The Central Power Purchasing Agency (CPPA), which purchases power from all generating stations is mandated to enable a competitive and bilateral market for power purchase. This enables better price discovery and an increased investment in renewables as solar and wind power are the cheapest sources of energy in Pakistan.

Meteorology

The Pakistan Meteorological Department (PMD) was established in 1947, breaking away from the Central Meteorological Organization operating over the Indian subcontinent. The department has five regional meteorological centres (RMCs) serving as administrative units for different regions.

For weather forecasting, the numerical weather modelling system deployed by Pakistan's meteorological department uses output derived from coarse resolution (100-300 km) global weather models as well as high resolution (~11 km) regional weather models on an operational basis. For insights into the broader features prevailing over the area of interest, Pakistan's meteorological department relies on the global model called GCM20 (Global Circulation model run at 20 km horizontal resolution). The model was developed at the Earth Simulator Centre, Yokohama Institute for Earth Sciences, Japan. The meteorological agency also relies on the Global Spectral Model (GSM)-based short- and medium-range forecasts at a spatial resolution of about 30 km. The forecast span extends up to a week ahead on a 12-hourly basis. The update cycle for the same is scheduled at 00 UTC i.e. at midnight every day, a new forecast is issued.

The forecasting tools used by Pakistan's meteorological agency to generate weather/climate forecasts at the city scale include high resolution model (HRM), Regional Climate Model Version 4 (RegCM4) and the Providing Regional Climates for Impacts Studies (PRECIS) platform. HRM was developed by the Deutscher Wetterdienst (DWD) National Meteorological Service of Germany. The initial conditions for the model run are derived from DWD's in-house global weather model. The deployment of the regional scale weather model by PMD has enhanced the accuracy of weather predictions owing to its capability to resolve mesoscale atmospheric signatures.

To generate forecasts over an extended time period at a city-scale, PMD uses Regional Climate Model (RegCM4) developed by the International Centre for Theoretical Physics in Italy (ICTP) and PRECIS, a regional climate modelling system conceived by the UK Met Office.

For the generation of short-term weather forecast, PMD uses the following tools namely, WRF model and global spectral model (GSM). WRF is configured to run on an operational basis at spatial resolution of 5 km whereas GSM is configured at a horizontal resolution of ~20 km. Both models generate weather forecasts for up to three days ahead. The spectrum of tools deployed by PMD for generating medium-range weather forecasts include Global Forecast System (GFS), Global Ensemble Prediction Suite (GEPS) and Global Environmental Multiscale Model (GEM). GFS forecasts span across the 3-7-day timeline and provide meteorological information at a resolution of 25 km. GEPS forecasts are generated twice a day by merging 63 global forecast products and remains available at one-degree spatial resolution (~100 km) with a temporal resolution of 6 hours[22]. The short/medium range forecast products at the disposal of PMD has a strong potential to provide valuable meteorological insights in order to cater to the requirements of solar and wind energy sectors.

Wind and Solar Forecasting

All wind and solar power generators that sell power to the CPPA face the risk of curtailment in spite of having a 'must-run' status as there is no operationally mandated forecasting or scheduling mechanism in place, which will allow for the CPPA to securely integrate such power sources. A forecasting exercise carried out on an operational basis by CPPA will prove beneficial to the growth of renewable power in the country in the absence of 'capacity payments' afforded to the conventional generation independent power producers (IPPs).

[22]Short/medium range forecasts accessible to Pakistan meteorological department- http://smrfc.pmd.gov.pk/

As understood from the primary research carried out for this study, wind and solar power forecasting is currently done by the IPPs and submitted to the relevant agencies (NTDC, CPPA). In addition, the Connection Code of the Grid Code mandates the provision of generation stations' static data collection in a standardised format to NTDC. The provision of a SCADA system, planned for upgradation, covers the aspect of dynamic data collection and monitoring of grid connected wind and solar plants. This enables accurate wind and solar power forecasting.

3.2.8 Sri Lanka

Installed wind and solar capacities in Sri Lanka stand at 129 MW and 160 MW, respectively in CY2019, with expansion to 800 MW and 1,900 MW anticipated by 2031. This puts Sri Lanka in third place in terms of wind and solar power generation penetration among the SAARC nations after India and Pakistan.

Ceylon Electricity Board (CEB) is the major electricity utility in Sri Lanka that is a vertically integrated entity, encompassing generation, transmission and distribution of electricity. The Lanka Electricity Company (LECO) is the other utility serving towns along the western coast of the country. LECO is owned partially by the CEB. SLSEA, established in 2007, is focussed on the growth and development of the renewable energy sector in the country.

Meteorology

The Department of Meteorology (DOM) in Sri Lanka acts as the focal point for the dissemination of weather services relevant to the aviation industry, marine sector, hydrology, agriculture, including both the private and public factions. The key institution within the DOM ecosystem responsible for the generation/dissemination of meteorological insights is the National Early Warning Meteorological Centre. It comprises the General Forecasting Division, Marine Weather Forecasting Division, Numerical Weather Prediction Division, Observation and Plotting Division, National Tsunami Warning Centre and Communication Division. In addition to the aforementioned services, DOM also maintains an up-to-date weather/climatological database and issues specialized forecasts on inclement weather (e.g. cyclone, rain, heavy rainfall, etc.) warnings.

DOM has access to a well-maintained weather observation network that spans across Sri Lanka. It comprises 23 synoptic stations, 4 upper air stations, 40 agro-met stations, 37 automated weather stations and a rain-gauge network. The synoptic stations measure meteorological parameters, including temperature, rainfall, atmospheric pressure, wind speed, direction and relative humidity.

Currently, weather forecasting at DOM is implemented using subjective methods guided by numerical weather products. Forecast products derived from IMD and ECMWF are heavily relied upon to guide the forecasting efforts at the National Early Warning Meteorological Centre. The NWP systems, as explored by DOM, still remains nascent with the meteorological department deploying the next generation mesoscale numerical weather model WRF on an experimental basis to generate forecasts up to five days ahead. The initial/boundary conditions for the regional-scale limited area model run were derived from global model runs. Using statistical and dynamical methods, the institution also generates seasonal forecasts for its stakeholders in the agriculture/irrigation sector using multiple gidded output from advanced global models[23]. DOM is currently attempting to address the meteorological requirements essential for flood warning systems with the help of an in-house configured weather model. Within this context, DOM has configured a WRF mesoscale model at multiple spatial resolutions with varying lead times. One such configuration uses WRF and generates forecasts at a spatial resolution of 5 and 15 km across 42 vertical layers of the atmosphere by dynamic downscaling of 50 km GFS model output. The forecast spans cover up to 9 days ahead. Another mesoscale configuration deploys the WRF model configured with 50 vertical layers and uses the GFS 25 km output as initial/boundary conditions.

The NWP systems of DOM can be used to meet the short/medium term weather requirements demanded by the renewable energy sector. The weather output derived from the in-house mesoscale model can be leveraged to benefit the energy generation forecasts associated with wind and solar energy sectors. Moreover, access to a well-established weather observation network can also be capitalised on to improve the accuracy of weather forecasts and facilitate prompt monitoring of its quality.

Wind and Solar Forecasting

In 2014, Sri Lanka achieved the target of generating 10% of its power through renewable energy. As the penetration of renewable energy increases, an increasing component of wind and solar power brings associated risks of grid imbalances due to variability in supply. As of today, most of the variability is addressed through the use of hydro plants and any changes in the monsoon patterns affect the country significantly in terms of managing grid stability. A lack of wind and solar power forecast would only exacerbate the risks involved. Furthermore, the country has pledged to use only renewable power for 100% of its electricity consumption at the 22nd United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties in Marrakech, Morocco, as part of the Climate Vulnerable Forum. That said, with high penetration of variable renewable energy of the sort generated by solar and wind power plants, integration of these plants will be successful only with advanced forecasting systems in place.

Wind and solar power generators are expected to carry out unit commitment activities for a horizon of 2-6 hours ahead using forecasting done with the help of private vendors and the utility itself does not carry out forecasting. As it stands, based on information collected from primary research surveys, private agencies for forecasting have been engaged in Sri Lanka to carry out forecasting of wind and solar generation by some of the generators themselves. The grid operation utility does not perform forecasting themselves and instead rely on dispatch plans by the wind and solar generators to manage their grid integration. In total, forecasting has not been deployed in the country extensively to manage the grid integration of wind and solar power.

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[23] *The World Bank. Weather and Climate services in Sri Lanka. Web link -* http://pubdocs.worldbank.org/en/976511542124485653/MMPMendis-SRILANKA WeatherAndClimateServicesinSriLanka.pdf

3.3 Policy and regulatory stance

This section discusses the different policies pertaining to wind and solar forecasting in each SAARC member state. In countries where there are no wind and solar forecasting policies at present, the overall context and need for forecasting has been discussed.

3.3.1 Bangladesh

All entities connected to the grid must abide by the Electricity Grid Code as defined by the BERC in 2018. As per the provisions of the grid code, every generator, whether new or existing, is under instruction to maintain SCADA systems for monitoring and control of the generation stations. In the case of existing stations, the TSO will maintain the SCADA systems, but as most wind and solar generation plants will be newly installed, the generators take on the responsibility of maintaining the SCADA equipment. Sharing the data collected by SCADA with the load dispatch centres and TSOs can be easily facilitated in this case which is conducive to the forecasting of wind and solar power generation by the generators themselves or the utilities. Variable renewable energy generators find mention in the grid code with detailed requirements for compliance with frequency and active power injection guidelines that seek to maintain grid stability. However, the code states a requirement for backdown of active power injection into the grid in case of frequency disturbances.

There is an additional requirement for RE generators, including wind and solar power generation plants, to submit power generation forecasts at an hourly time-resolution along with their availability on a day-ahead basis. Beyond this, there is no mechanism or requirement to incentivize forecasting of wind and solar power and achieve higher accuracies.

3.3.2 India

Regulations such as the 'Renewable Regulatory Fund' superseded by the 'Forecasting and Scheduling' regulations have allowed for the growth of private sector participation in forecasting. Government organisations such as the National Institute of Wind Energy (NIWE) and the National Institute of Solar Energy (NISW) also play a role in the promotion of wind and solar technologies in India. India also has a mature meteorological department providing multiple products and services towards the growth of wind and solar power capacity expansion and forecasting.

Wind and solar power forecasting in India are mandated for generators through the Forecasting and Scheduling regulations (FnS) which superseded the erstwhile Renewable Regulatory Fund regulations. The FnS regulations define acceptable error bands for wind and solar forecasts and deviations from the error bands are penalised financially. These regulations are implemented by the nodal agencies of each of the federal states that have significant wind and solar penetration. Under these regulatory frameworks, the wind and solar power generators are at liberty to generate and provide their own forecasts or assign such responsibilities to Qualified Coordination Agencies (QCAs) that may perform such responsibilities on behalf of the generators.

There is little variation between the states in their respective regulations. Only two states allowing for aggregated forecasting of multiple sites, which as explained earlier, result in lower errors for the pool compared with the forecasts of individual sites.

This regulatory framework has allowed for the development of advanced forecasting techniques in India focussed on reducing financial penalties arising from non-compliant forecast accuracies.

However, these regulations have led to a focus on the short-term horizon of 0.75-1.5 hours ahead as the financial implications are only applicable in these time-frames. As a consequence, short-term forecasting has improved significantly over the years. Forecasting for longer horizons is also carried out with a lesser focus on accuracies.

3.3.3 Pakistan

To ensure the smooth and efficient functioning of the grid and its participants, the NTDC has published a Grid Code. The NTDC's Operational Code under the Grid Code defines a system frequency tolerance band of 49.5 Hz to 50.5 Hz, beyond which, action will be taken to protect the stable operation of the grid. In order to have control over the grid frequency, it is critically important to manage a demand-supply balance, which, in the case of intermittent generation into the grid from renewables, will be put at risk. The current installed capacities do not pose an immediate risk to grid stability, but with increasing penetration, the effect of wind and solar power injection into the grid will be significant. In order to minimise the risk of instability, supply from wind and solar power generation plants must be forecasted at least a day in advance, in line with the planning timelines of NTDC.

The Scheduling and Dispatch Code of the Grid Code also specifies the requirement of all centrally dispatched generation units (CDGUs) to submit notices of their availability (Availability Notice) for generation in advance of the 'Schedule day'. Based on the Availability Notices and the demand forecasts prepared, NTDC prepares schedules for all generators to abide by. Such a framework does not take into account the flexibility in scheduling required for integration of large amounts of wind and solar power into the grid. It is expected that with an increase in renewable energy penetration at the transmission grid level and with a bilateral power market coming into existence, changes in the grid code will follow, which will require continuous operational forecasting and scheduling of wind and solar power generation.

3.3.4 Sri Lanka

The management of the electric grid, as in other countries, is governed by the rules and regulations listed in the Grid Code. In the absence of renewables-specific grid management regulations, the Grid Code serves as the overarching regulatory framework for grid management. The Grid Code of the CEB provides for the SCADA system to be installed and maintained by the transmission licensee for every connection point to the grid, including generators, which cover the dynamic data requirements for forecasting to be carried out by the utilities. There is special mention given to include Intermittent Resource Based Generation Stations (IRGBS) connected directly to grid substations. As per the primary research responses, 50% of the wind and solar power plants have been covered by SCADA links. SCADA links are being established for the remaining power plants.

The Grid Code also specifically mentions under 3.17.5, that the curtailment of IRBGS is dependent on the reliability of wind power forecasts, which would be equally applicable to solar stations as well. The Generation Dispatch Code of the Grid Code includes daily, monthly, rolling and annual dispatch (year ahead) plans which are based on generation forecasts inclusive of IRBGS (solar and wind).

The planning data requirements cover the static data needed for establishing forecasting systems in detail under the Wind Power and Solar Power Generation Facilities requirements. Given the detailed nature of the grid code in Sri Lanka, prerequisites for forecasting have been established well. However, as per the primary research conducted for the purpose of this report, location coordinates which are an integral part of the forecasting system requirements are not available with grid operators. This gap can be filled easily with initiative from any of the electricity utility departments.

As per the grid code, the onus is on the transmission licensee to generate forecasts for dispatch, which would also include wind and solar power generation. This responsibility is further passed along as all IRBGS of 5 MW or above are required to submit a year-ahead rolling dispatch plan, updated monthly with forecast generation. The system operator shall include this forecast generation in dispatch planning.

3.3.5 Other SAARC Member States

The rest of the SAARC Member States have not formulated any regulations for wind and solar forecasting. This is due to lack of penetration of renewable energy in the power supply mix as well as lack of maturity of overall power markets. However, with all countries envisaging to improve injection of wind and solar power over the next decade, it is imperative for the countries to firm up regulations as well as an implementation framework.

3.4 GAP Analysis

For all SAARC Member States apart from India, a strong wind and solar forecasting ecosystem is in the nascent stage or absent. This does not bode well as all these countries intend to augment renewable power generation over the next 10 years. As indigenous gas supplies have been tapering off in countries such as Bangladesh and Pakistan, planning bodies have been laying emphasis on cleaner renewable energy sources. Afghanistan, Bhutan, Nepal and the Maldives have been intending to curb electricity imports and tap into renewable resource potential. Sri Lanka, on the other hand, despite being 100% grid-connected, aims to achieve carbon neutrality by augmenting renewable energy (wind and solar) into a hydro and coal dominant power supply system.

Although the intent for governments to shift towards renewable sources of energy is novel, adoption of sound forecasting methodology for wind and solar power needs to be happen simultaneously. The flexibility (or infirmness) of wind and solar power needs to be gauged by their ramp rates, response accuracy, run times and off times as well as minimum generation levels. Although flexibility in generation fleet can improve load following responsiveness in the system, lack of forecasting will prove detrimental to transmission and distribution infrastructure of countries, leading to power system failures and unreliable power supply.

An assessment tool is proposed for evaluation and scoring of each nation’s current status of wind and solar forecasting with the major criteria for assessment as defined in Table 16:

Table 16: Rating Scale of Wind and Solar Power Forecasting for SAARC Member States

Criteria	Area of assessment	Score
Static data collection framework	Collection and record-keeping of all the static information of wind and solar plants such as plant characteristics, location coordinates and manufacturer-provided generation characteristics	0 - No static data collected 0.5 - Static data collected 1 - Static data collected via standardised framework

Criteria	Area of assessment	Score
Dynamic data collection	Monitoring the generation, availability data of the solar and wind plants through the establishment of data acquisition and monitoring systems.	0 - No dynamic data collected 0.5 - Dynamic data collected in real-time as part of existing system integration 1 - Dynamic data collected in real-time via renewable energy-specific framework
Independent NWP	Capability of the nation to carry out numerical weather predictions of weather parameters relevant to wind and solar power forecasting	0 - No data available 0.5 - Data available 1 - Models operational and data available
Short-term wind power forecasting	Wind power forecasting on short range time horizon i.e. 0-23 hours ahead	0 - Not operational 0.5 - Operational and not mandated 1 - Operational and mandated by regulation
Medium-term wind power forecasting	Wind power forecasting on medium range time horizon i.e. 24-360 hours ahead	0 - Not operational 0.5 - Operational and not mandated 1 - Operational and mandated by regulation
Long-term wind power forecasting	Wind power forecasting on long range time horizon i.e. 16-90 days ahead	0 - Not operational 0.5 - Operational and not mandated 1 - Operational and mandated by regulation
Short-term solar power forecasting	Status of solar power forecasting on short range time horizon i.e. 0-23 hours ahead	0 - Not operational 0.5 - Operational and not mandated 1 - Operational and mandated by regulation
Medium-term solar power forecasting	Status of solar power forecasting on medium range time horizon i.e. 24-360 hours ahead	0 - Not operational 0.5 - Operational and not mandated 1 - Operational and mandated by regulation
Long-term solar power forecasting	Status of solar power forecasting on long range time horizon i.e. 16-90 days ahead	0 - Not operational 0.5 - Operational and not mandated 1 - Operational and mandated by regulation
Dispatch of wind and solar power	Wind and solar power generation management by the grid operators for unit commitment and dispatch	0 - Not managed 0.5 - Dispatch managed through operator expertise

Criteria	Area of assessment	Score
		1 - Dispatch managed through forecast-driven plans

The status of each assessment criterion may fall under:

- Operational - Already established and operational
- In progress - In the process of development
- Lacking - Not available and no work in progress
- No information - Indicates a lack of information to assess the state

Eventually, a final score in the range of 1-10 is provided to quantify the gaps in the countries' readiness for forecasting of wind and solar power. In the absence of information available for any of the criteria, a minimum score is assigned. In such cases, the table and scoring criteria may be used for self-evaluation by the relevant organisations and their status gauged against a maximum score of 10. The scores of other SAARC nations may also be used for comparative analysis.

Based on the above evaluation criteria, each SAARC Member State has been evaluated and ranked to assess the overall preparedness or non-preparedness with respect to wind and solar power forecasting.

3.4.1 Afghanistan

Table 17: Gap Analysis for Afghanistan

Criteria	Status	Score
Static data collection framework	No information	0
Dynamic data collection	No information	0
Independent NWP	In progress	0.5
Short-term wind forecasting	Lacking	0
Medium-term wind forecasting	Lacking	0
Long-term wind forecasting	Lacking	0
Short-term solar forecasting	Lacking	0
Medium-term solar forecasting	Lacking	0
Long-term solar forecasting	Lacking	0
Dispatch of wind and solar power	Lacking	0.5
Total score		1

Total score for Afghanistan is 1/10

Afghanistan is in very early stage of developing wind and solar power forecasting. The gaps in the system are:

- Meteorological prowess is not sufficient to support indigenous forecast development
- Infrastructure gaps in data collection, transmission and storage
- Lack of policy frameworks to drive development of wind and solar forecasting
- Lack of forecast utilisation in the grid operation process

3.4.2 Bangladesh

Table 18: Gap Analysis for Bangladesh

Criteria	Status	Score
Static data collection framework	Operational	0.5
Dynamic data collection	Operational	0.5
Independent NWP	Lacking	1
Short-term wind forecasting	Operational	0.5
Medium-term wind forecasting	Lacking	0
Long-term wind forecasting	Lacking	0
Short-term solar forecasting	Operational	0.5
Medium-term solar forecasting	Lacking	0
Long-term solar forecasting	Lacking	0
Dispatch of wind and solar power	Lacking	0.5
Total score		3.5

Total score for Bangladesh is 3.5/10

The country as of now does not need forecasting of wind and solar power for grid operations and so it is in early stage developing such a system. The gaps that exist in multiple areas are:

- Lack of policy frameworks to drive development of wind and solar forecasting
- Limited data collection and transmission infrastructure
- Limited forecast utilisation in the unit commitment process

3.4.3 Bhutan

Table 19: Gap Analysis for Bhutan

Criteria	Status	Score
Static data collection framework	Operational	1
Dynamic data collection	Operational	0.5
Independent NWP	Operational	0.5
Short-term wind forecasting	Operational	0.5
Medium-term wind forecasting	Lacking	0
Long-term wind forecasting	Lacking	0
Short-term solar forecasting	Operational	0.5
Medium-term solar forecasting	Lacking	0
Long-term solar forecasting	Lacking	0
Dispatch of wind and solar power	Lacking	0.5
Total score		3.5

Total score for Bhutan is 3.5/10

Bhutan's wind and solar forecasting in operational but it has limited utilisation. Gaps exist in the distribution of forecast responsibility and dispatch scheduling of generators using forecasts. The issues with the system are:

- Lack of generator participation in the forecasting process
- Lack of policy frameworks to drive development of wind and solar forecasting
- Meteorological prowess is not sufficient to meet requirements of all forecast time horizons

3.4.4 India

Table 20: Gap Analysis for India

Criteria	Status	Score
Static data collection framework	Operational	1
Dynamic data collection	Operational	1
Independent NWP	Operational	1
Short-term wind forecasting	Operational	1

Criteria	Status	Score
Medium-term wind forecasting	Operational	1
Long-term wind forecasting	Lacking	0
Short-term solar forecasting	Operational	1
Medium-term solar forecasting	Operational	1
Long-term solar forecasting	Lacking	0
Dispatch of wind and solar power	Operational	1
Total score		8

Total score for India is 8/10

India has relatively advanced system for forecasting of wind and solar power. However, there are areas that need improvement to ensure higher levels of integration of wind and solar power into the grid:

- 45-60 minutes delay in forecast applicability in the regulatory framework. This leads to the most accurate portion of the forecasts, i.e. the most near to real-time period being missed out in forecast considerations
- Lack of attention on forecast qualities on a multi-horizon scale. Most of the focus lies on forecasts after intra-day revisions
- Lack of uncertainty planning by using probabilistic forecasts

3.4.5 Maldives

Table 21: Gap Analysis for Maldives

Criteria	Status	Score
Static data collection framework	Lacking	0.5
Dynamic data collection	Lacking	0
Independent NWP	Lacking	0.5
Short-term wind forecasting	Lacking	0
Medium-term wind forecasting	Lacking	0
Long-term wind forecasting	Lacking	0
Short-term solar forecasting	Lacking	0
Medium-term solar forecasting	Lacking	0
Long-term solar forecasting	Lacking	0
Dispatch of wind and solar power	Lacking	0

Criteria	Status	Score
Total score		1

Total score for Maldives is 1/10

Maldives has one of the lowest penetrations of wind and solar power among SAARC nations. The mismatch between the current RE capacity in the country and the generation required is significant. The following are the gaps in the system:

- Meteorological prowess is not sufficient to support indigenous forecast development
- Infrastructure gaps in data collection, transmission and storage
- Lack of policy frameworks to drive development of wind and solar forecasting
- Lack of forecast utilisation in the grid operation process

3.4.6 Nepal

Table 22: Gap Analysis for Nepal

Criteria	Status	Score
Static data collection framework	Operational	1
Dynamic data collection	Partially	0
Independent NWP	Partially	0.5
Short-term wind forecasting	Operational	0
Medium-term wind forecasting	Operational	0
Long-term wind forecasting	Operational	0.5
Short-term solar forecasting	Operational	0
Medium-term solar forecasting	Operational	0
Long-term solar forecasting	Operational	0.5
Dispatch of wind and solar power	Operational	0
Total score		2.5

Total score for Nepal is 2.5/10

As Nepal's wind and solar capacity additions are in nascent stages, so is its forecasting capability. The mismatch between the current RE capacity and the generation required is large. The gaps in the system are:

- Meteorological prowess is not sufficient to support indigenous forecast development
- Infrastructure gaps in data collection, transmission and storage
- Lack of policy frameworks to drive development of wind and solar forecasting

- Lack of forecast utilisation in the grid operation process

3.4.7 Pakistan

Table 23: Gap Analysis for Pakistan

Criteria	Status	Score
Static data collection framework	Operational	1
Dynamic data collection	Operational	0.5
Independent NWP	In progress	1
Short-term wind forecasting	Operational	0.5
Medium-term wind forecasting	Operational	0.5
Long-term wind forecasting	Lacking	0
Short-term solar forecasting	Operational	0.5
Medium-term solar forecasting	Operational	0.5
Long-term solar forecasting	Lacking	0
Dispatch of wind and solar power	Lacking	0
Total score		4.5

Total score for Pakistan is 4.5/10

Wind and solar forecasting in Pakistan is at a stage where further development is possible in several areas. Generators participate in forecasting and the data is shared with grid operators. However, policy and regulatory frameworks can further formalize this process. Gaps in the following areas need attention:

- Lack of policy frameworks to drive development of wind and solar forecasting
- Lack of benchmarks around expected accuracies in forecasts
- Limited forecast utilisation in the unit commitment process

3.4.8 Sri Lanka

Table 24: Gap Analysis for Sri Lanka

Criteria	Status	Score
Static data collection framework	Operational	0.5
Dynamic data collection	Partially	0.5
Independent NWP	Partially	0.5

Criteria	Status	Score
Short-term wind forecasting	Operational	0.5
Medium-term wind forecasting	Operational	0.5
Long-term wind forecasting	Operational	0
Short-term solar forecasting	Operational	0.5
Medium-term solar forecasting	Operational	0.5
Long-term solar forecasting	Operational	0
Dispatch of wind and solar power	Operational	0.5
Total score		4

Total score for Sri Lanka is 4/10

Sri Lanka has forecasting embedded as a requirement in its grid code. However, limited importance is accorded to forecasting and its utilisation. There is scope for further development and Sri Lanka is in a good position to start the process of forecasting system development and deployment. The areas that need to be addressed are:

- Lack of policy frameworks to drive development of wind and solar forecasting
- Limited data collection and transmission infrastructure
- Lack of standardized forecast requirements from the grid operation perspective
- Lack of benchmarks around expected accuracies in forecasts
- Limited forecast utilisation in the unit commitment process

4 IMPLEMENTATION OF WIND AND SOLAR FORECASTING TECHNIQUES IN SAARC MEMBER STATES

This section discusses challenges in the implementation of wind and solar forecasting techniques in the SAARC Member States. Each country has been evaluated separately to understand the impending challenges exhaustively.

4.1 Challenges for Setting up of Forecasting Techniques

This section highlights the key challenges posed by countries while implementing RE forecasting techniques.

4.1.1 Policy and Regulatory

Factor 1: Regulatory Stance towards RE

Afghanistan

The Ministry of Energy and Water (MEW) has come up with a renewable energy roadmap for Afghanistan, titled *RER 2032,* under which the country aims to set up 5,000 MW of RE-based generation by 2032. The Afghanistan Renewable Energy Policy's targets and vision align with this. The country's RE development strategy is based on the Afghanistan National Development Strategy (which provides vision and goals for the energy sector), Power Sector Master Plan 2013 (which provides overall status and priorities of the power sector planning), and National Energy Supply Program 2013 (which has set targets for electricity supply and renewable energy sector until 2022). More recently, the Renewable Energy Policy 2015 has set RE targets for 2032. Out of this, utility-wise wind and solar targets have been set at 926.5 MW and 600 MW respectively.

Table 25: Technology-wise Contribution for Meeting RENP Targets

Market	Technology	Target capacity (MW)
Utility scale	Solar PV	926.5
	Wind	600
	Large hydro	2,000
	Others (biomass, waste to energy, geothermal)	143
Mini grid	Hybrid	300
	Hydro	420
Stand-alone	Solar PV	606.6
	Others (biomass, waste to energy, geothermal)	6.7
Total		5002.7

Source: MEW

Bangladesh

The country had formulated its first RE policy in 2008, which set a target to generate 5% of electricity from RE by 2015 and 10% by 2020. The Sustainable and Renewable Energy Development Authority

(SREDA) Act was passed in December 2012 to promote, develop and coordinate RE and energy efficiency programmes in the country. Bangladesh continues to promote and encourage solar home system (SHS) and mini/ micro grids to improve energy access in remote rural areas. This is to support and achieve the government's vision of electricity for all by 2021. However, long-term utility-scale RE targets have not been firmed up at the policy level. Further, there is no regulated tariff structure/ incentive for large-scale solar and wind projects.

Bhutan

MOEA, Bhutan, plays a central role in the formulation of energy sector policies through its three departments – the Department of Hydropower and Power Systems (DHPS); the Department of Renewable Energy (DRE); and the Department of Hydromet Services. DRE is the nodal agency for the implementation of the renewable energy policy. The Alternate Renewable Energy Policy (AREP), aimed at promoting and developing RE in the country, had come up with RE targets for the country. The Renewable Energy Policy 2011 had stated that the country shall strive to generate 20 MW by 2020 through a mix of the following technologies: *a)* solar - 5 MW; *b)* wind- 5 MW; *c)* biomass- 5 MW and *d)* Others- 5 MW (includes cook stoves, solar water heaters, biogas, hybrid systems etc). In 2016, a study titled *Renewable Energy Master Plan* conducted by DRE-MOEA estimated technical potential of wind and solar in the country and came up with an RE master plan, providing alternative scenarios. More recently, the five-year plan (FYP) for 2018-2023 highlighted the deployment of pilot RE projects.

Table 26: RE Scenarios Proposed by the Renewable Energy Master Plan (In MW; As of 2025)

Technology	Low case	Base case	High case
Small hydropower	37.2	67.5	110
Wind	2.4	5.1	7.8
Solar PV	2	6.1	11.9
Biomass	0.6	1	8.1
Total	42.2	79.7	137.8

Source: DRE

India

The key legislation guiding the development of RE in India is the Electricity Act, 2003, which mandates state electricity regulatory commissions (SERCs) to promote renewable sources. The Ministry of Power has proposed a National Renewable Energy Policy in the draft Electricity (Amendment) Bill, 2020. The policy aims to promote RE by prescribing a minimum offtake target from renewable and hydro sources.

The government's target is to achieve 175 GW of grid-connected renewable electricity by March 2022 – 100 GW solar, 60 GW wind, 10 GW biomass and 5 GW of small hydropower. In addition, the Ministry of New and Renewable Energy (MNRE) is targeting 1 GW of geothermal capacity by 2022. The 2018 National Electricity Plan has an ambitious target to achieve 275 GW of RE by 2027, which would increase its share to 44% of installed capacity and 24% in electricity generation.

Maldives

In 2015, the Republic of Maldives had stated that it intends to install RE generation capacity that meets up to 30% of daytime peak load in all inhabited islands by 2019. It had also introduced policies for targeted electricity subsidies, import duty exemptions for renewable energy products, and net metering. Over the years, the country partnered with several multilateral agencies such as International Renewable Energy Authority (IRENA), and Climate Investment Funds (CIF) to devise an RE implementation roadmap. Several small-scale programmes were adopted in some of the islands to set up solar PV-battery-diesel hybrid energy systems or off-grid wind installations. However, these programmes are funded through grants or loans received from international or donor agencies. This restricted implementation and capacity building. There are no RE-based policies at the federal level.

Nepal

The country had established an Alternative Energy Promotion Centre in 1996 to improve household-level rural energy supply through solar and micro-hydro projects and to promote biogas for cooking. An RE policy was framed in 2006. The government of Nepal has also set out goals to increase the share of RE to 10% of total energy supply by 2030. The country has introduced an RE subsidy policy in 2012, which was amended in 2016. The policy aims to develop the RE sector by providing subsidy to very poor households for deployment of renewables. It primarily focusses on off-grid applications and provides subsidies for mini/ micro hydropower, improved water mill, solar energy (home systems, mini-grids, grid connected), biogas, biomass energy, wind energy and wind-solar hybrids. However, there is no policy targets to set up utility-scale RE projects in Nepal. The government has not devised any roadmaps or implementation strategies to develop grid-connected, utility-scale wind and solar installations.

Pakistan

The RE Policy 2006 had kick-started the development of RE in Pakistan. After its expiry in 2018, the country drafted a new RE policy, Alternate and Renewable Energy Policy (ARE) 2019. The new policy targets ARE (includes solar, wind, biomass, ocean/ tidal energy, geothermal, and energy to waste) to account for 20% of total generating capacity by 2025 and 30% by 2030. The government plans to set up ~18 GW of RE by 2030. Other RE support initiatives include: *a)* prioritisation of allocation of land to RE projects; *b)* open and transparent pricing based on competitive pricing for RE technologies; and *c)* net metering arrangements for residential, commercial and industrial consumers to feed self-generated surplus power into the grid.

Sri Lanka

The country, being one of the 195 signatories to the Paris Agreement, has shown its commitment towards addressing climate change through its energy commitments and policy reform. In order to further the country's RE development, SLSEA was established in 2007 under the purview of the Ministry of Power and Renewable Energy (MPRE).

In 2016, Sri Lanka set a national target to increase RE capacity by 32% by 2050. In August 2019, the island nation adopted the National Energy Policy and Strategies, which aims to reduce by 2030 its dependence on fossil fuels to below 50% of the primary energy supply and to cut the specific energy use across all end-uses by 20% of 2015 level. In the power sector, the country has set an ambitious target to reach 100% electricity generation through RE (including large hydro) by 2050.

Overall, on RE policy and regulation, each country's performance varies. While India has taken strides in developing an RE ecosystem through strong policies, countries such as Afghanistan and the Maldives have weak RE policies. This has led to varying degrees of RE penetration among SAARC Member States, despite most of them having high RE potential. The authors assessed RE policies of these countries using two metrics – availability of the latest RE policy and its implementation strength. While almost all of them had RE policies, some of them were dated (for instance, Afghanistan and Maldives). In case of some other countries, like Bangladesh, the government has set no specific medium- and long-term RE targets. This creates roadblocks to achieve desired results and, in turn, hinder investments. The second metric – implementation strength – assessed the efficacy of the federal policies. While policies are the framework for RE development, their impact on the ground may vary between geographies depending on their effectiveness in addressing challenges and providing incentives for the development. Implementation strength of policies has been assessed further based on two parameters: *i)* guidance towards achieving policy targets; and *ii)* how effective were previous policies in achieving targets. Using a combination of these two sub-parameters, we have devised a metric. Taking all parameters and sub-parameters into consideration, we have arrived at a final metric. To prevent skewness in results while evaluating the performance, SAARC Member States were not benchmarked with the best (and developed) nations. Also, while evaluating RE policies and their implementation, the scope has been limited to utility-scale installations. Distributed generation through development of off-grid and micro grids have not been looked at.

While it is difficult to rate a country's RE policies objectively, the study has bucketed countries based on the assessment criteria presented below:

Table 27: Methodology of Assessment of RE Policies in SAARC Member States

Metric	Evaluation criteria	Rating
Availability of latest RE policy	Latest RE Policy: Available RE targets: Available	High
	Latest RE Policy: Available RE targets: Not Available	Medium
	Latest RE Policy: Not Available RE targets: Not Available	Low
Strength in policy implementation	Guidance towards achieving policy targets: Strong Previous policy achievements: Strong	High
	Guidance towards achieving policy targets: Moderate Previous policy achievements: Moderate	Medium
	Guidance towards achieving policy targets: Weak Previous policy achievements: Weak	Low

Table 28: Outcome of Assessment of RE Policies in SAARC Member States

Country	Availability of latest RE policy	Strength in policy implementation	Overall
Afghanistan	Low	Low	Low
Bangladesh	Low	Medium	Low
Bhutan	Medium	Medium	Medium
India	High	Medium	High
Maldives	Low	Low	Low
Nepal	Low	Low	Low
Pakistan	High	Low	Medium
Sri Lanka	High	Medium	Medium

Factor 2: Availability of Policies Mandating Solar and Wind Forecasting

As discussed in Section 3.3, India has the most detailed and comprehensive policies for forecasting of wind and solar energy. Bangladesh, Sri Lanka and Pakistan have policies in place, but are in nascent stages. For each of the three nations, power generators have to undertake forecasting and submit it to the grid operator. However, the rules and measures are still not developed enough and, unlike India, punitive measures have not been specified in policies in case of forecasting and scheduling errors. In Afghanistan, the Maldives, Bhutan and Nepal, there are no solar and wind forecasting policies as of now.

Factor 3: Mandating Utilities/ Generators to Buy RE

In order to improve RE offtake, *India*, the most mature country among SAARC Member States, has laid down rules to promote renewable purchase obligations (RPOs) and renewable electricity certificates (RECs). RECs require distribution companies (DISCOs), energy producers, and certain consumers to buy a share of their electricity requirement from RE sources. RPO trajectories and compliance monitoring are carried out by respective SERCs. The obligated entities use RECs to comply with their RPO requirements. The Central Electricity Regulatory Commission (CERC) introduced voluntary RECs in 2010 and allowed their trading in 2011 to address the discrepancies between the availability of electricity from RE sources across regional markets and demand from obligated utilities and customers to meet their RPOs. CERC has enforced the REC programme subsequently.

Bangladesh has accorded must-run status to RE plants. The energy from these plants would be despatched by the system operator at all times, and will be subjected to backing down only in system emergency conditions or in case of transmission constraints. The policy covers utility-scale and rooftop installations. However, as the country has a single buyer system, electricity is purchased at rates agreed upon in PPAs and DISCOs are not mandated to buy RE.

In the case of *Sri Lanka*, renewables are still not competitive like hydro and oil-based plants. The country has been providing subsidies to improve RE penetration. At present, must-run status has not been accorded to RE plants and it is also not mandatory for utilities to buy energy from them.

As per the RE policy of *Bhutan*, the transmission utility is required to provide access to power from RE projects, and IPPs will be allowed to sell power directly to consumers or to a distribution company. However, the local distribution utility would have the first right of refusal for purchase of power. The policy further seeks to establish a Renewable Energy Development Fund (REDF) to be managed by the nodal agency, which will promote RE projects. The fund would also be used to compensate distribution utilities for the difference between the feed-in-tariff and the average power purchase price, if the regulated utility is mandated to purchase RE power. However, effective implementation of the policy is key.

In case of *Nepal, Pakistan, Afghanistan,* and *the Maldives*, where power demand far outstrips supply, it is not mandatory for utilities to buy RE. Demand-side push is created by governments either by providing capital subsidies or feed-in-tariffs to eligible RE projects to improve uptake. However, power markets in these countries are not mature enough to make RE buying by DISCOs or consumers mandatory.

4.1.2 Lack of Market Design and Institutional Framework

Afghanistan

Afghanistan's energy sector is managed principally by MEW, which formulates policies governing power, coal, gas, and other primary fuels. The power sector is operated by Da Afghanistan Breshna Sherkat (DABS), which controls and operates all activities in the sector throughout the country.

The prevailing power system in the country is weak and fragmented. Grid supply largely consists of imports from neighbouring countries. However, most of the power systems of countries serving Afghanistan's import needs are not synchronised, resulting in interconnection issues and islanding.

Before integrating large-scale RE into the system, the country will have to overhaul and strengthen its transmission and distribution network.

Bangladesh

The Power Division, Ministry of Power, Energy & Mineral Resources (MPEMR), is the apex institution overlooking the power sector in the country. Bangladesh Energy Regulatory Commission (BERC) is an independent and autonomous body, which regulates the power sector. Power is generated by Bangladesh Power Development Board (BPDB), subsidiaries of BPDB, IPPs and private power generation companies. Power is supplied through Power Grid Corporation of Bangladesh's (PBCB) power transmission facilities (the sole power transmission company) to customers in major urban areas by BPDB, in the metropolitan areas of Dhaka by DPDC and DESCO, and in rural areas by Palli Bidyut Samity (PBS). BPDB is the single buyer of power from generating stations based on negotiated bulk power tariff rates. It further sells electricity to the distribution utilities based on BERC regulated wholesale tariff rates.

Although the generation side has been able to attract private investments, transmission and distribution segments continue to be completely regulated by government entities. At present, a deregulated and competitive power market is absent. There is no power market and sales are solely on the basis of power quantum, as signed under long-term PPAs. MPEMR, in its report titled 'Assessment of Barriers to Implement Renewable Energy (RE) Projects' dated March 2019, concedes that Bangladesh's national grid is still not robust and reliable enough to absorb shock due to intermittent tying in and tying out RE power beyond a certain capacity. However, the government through its RE policy has been working towards making accommodative policies to attract investments in the RE sector.

Bhutan

The energy sector falls under the scope of the Ministry of Economic Affairs (MOEA) and Ministry of Agriculture and Forests. The MOEA performs key functions related to planning, monitoring and evaluation for the energy sector. Under the power sector, the Department of Hydropower and Power Systems (DHPS) is a planning and coordination body and is responsible for granting approval to the utility companies for development of hydropower, upgradation and expansion of transmission systems. The Department of Renewable Energy (DRE) was established in December 2011 with the mandate to serve as the central coordination agency and the focal point of the government on all matters related to RE development. Bhutan Power Corporation (BPC) distributes electricity throughout the country and provides transmission access for domestic supply as well as export. The state-owned BPC has had the main responsibility for transmitting and distributing of electricity, while Druk Green Power Corporation (DGPC), also state-owned, looks after power generation. DGPC is the holding company of all existing hydropower companies.

India

The power sector is overseen by the Ministry of Power (MoP). Central Electricity Authority of India (CEA) is a statutory technical wing of the MoP to assist in planning, coordination and regulation of power development programmes of the country. Central Electricity Regulatory Commission (CERC) is an independent statutory body, which regulates tariff-related matters and inter-state bulk sale of power, aids and advises the central government on the formulation of tariff policies, frames the guidelines on tariff, and promotes competition and efficiency in the electricity sector. The Ministry of New and Renewable Energy (MNRE) facilitates research, design, development, manufacture and deployment of new and RE in the country. On the power generation side, the central, state and private sectors have their own generation capacities, representing ~30%, ~25% and ~45% of the total installed power base, respectively. Power Grid Corporation of India Ltd (PGCIL), a central transmission utility (CTU), is responsible for planning inter-state transmission systems (ISTS) and state transmission utilities (STU) (namely state transco/ SEBs) responsible for the development of intra-state transmission system. Power System Operation Corporation Ltd (POSOCO) manages the national and regional grid from National Load Despatch Centre (NLDC) and five regional load despatch centres (RLDC) through unified load dispatch and communication facilities. In addition, private sector players also operate as transmission licensees. The responsibility for distribution and supply of power to rural and urban consumers rests with the states. Several DISCOs, both public and private, manage power distribution in the country. De-licensing in generation of electricity and open access in distribution of electricity brought through the Electricity Act, 2003, have led to unbundling, corporatisation and privatisation of the sector.

Power can transact on two exchanges, India Energy Exchange (IEX) and Power Exchange India Ltd (PXIL), which includes term ahead, day head and real-time power products. Recently, the government allowed electricity derivatives and forward contracts to be traded on commodity exchanges, which will give DISCOs more flexibility in long-term contracts.

However, several challenges remain. Some of the major power market challenges include: (a) most DISCOs in India are government-owned and vertically integrated. This leads to system inefficiencies and sub-par performance. (b) Slower-than-expected power demand growth, lack of PPAs, delayed payments by DISCOs have led to financial stress of coal-based power plants and stranded assets. (c) In the short-term market, liquidity constraints remain and a large proportion of transactions continue to occur outside the exchanges (bilateral contracts, direct transactions between DISCOs, under the deviation settlement mechanism), where prices are non-transparent.

Maldives

Maldives Energy Authority (MEA), under the Ministry of Environment and Energy, is a semi-autonomous regulatory body working under the guidance of a governing board appointed by the president. The regulator is mandated with establishing tariffs, issuing guidelines and regulations to ensure the reliability and security of the grids, and safeguarding the rights and obligations of consumers and service providers. Owing to the dispersed nature of the islands, the country has a separate power generation and distribution system operated by three utility companies: (a) State Electric Company Ltd (STELCO) generates and supplies electricity to Malé and adjoining islands. It operates ~35 power houses. (b) FENEKA Corporation Ltd (FENEKA) was established in 2012 by a presidential decree under the Companies Act of 10/96, as a limited liability company. It is a 100% government-owned utility company with a mandate to provide island communities with electricity, water, sewerage and waste management services. It operates 148 power houses. (c) Malé Water and Sewerage Company (MWSC) was established in 1995 and is the pioneer organisation in Maldives to institute a water production and wastewater management system. It operates its own powerhouse to serves ~50% of the Maldivian population.

The country's power market is government controlled and highly regulated. Majority of the population of Maldives continue to rely on distributed generation through mini/ micro grids. Due to the dispersed geographical position of the islands in the archipelago, transmission and distribution infrastructure is scattered and islanded, which restricts smooth operation of the power market.

Nepal

Nepal's energy sector is managed by the Ministry of Energy, Water Resource and Irrigation (MoE), Government of Nepal, which is responsible for policy formulation in the areas of power, coal and petroleum products. The Nepal Energy Regulatory Commission is entrusted with functions including technical management, tariff determination and organizational capacity building in power sector in the country. The Water and Energy Commission Secretariat (WECS) is a key administrative body that supports the MoE in the formulation of policies and planning of projects in the water and energy resources sectors. The Energy Commission is headed by the Minister of Energy. The Department of Electricity Development (DoED) assists in implementation of overall government policies related to power/electricity sector. The Nepal Electricity Authority (NEA) is responsible for the generation, transmission and distribution of power. It is also responsible for purchase of power from IPPs. The Alternative Energy Promotion Centre (AEPC), a government institution under the MoE, is responsible for promotion of renewable and alternative energy technologies in the country.

The power sector is highly regulated and vertically integrated. The country is a single-buyer market, where bulk purchases are made without competition. The sector structure impedes development and trade. Although, the country has set up cross-border power trade with neighbouring India to bridge the domestic supply deficit, there is no power market to cater to short-term requirements and the country solely relies on long-term bilateral contracts. However, the draft of New Electricity Policy (NEP) now recognises electricity trading as a business activity and includes provisions that generation, transmission and distribution businesses will be run by separate entities, i.e. no entity would be licensed for two businesses.

Pakistan

The Power Division under the Federal Ministry of Energy has oversight on power generation, transmission, distribution and pricing in Pakistan. The electricity sector is regulated by NEPRA. Power generation is provided by state-owned GENCOs for thermal power, Water and Power Development Authority (WAPDA) for hydropower as well as private IPPs. On the transmission side, state-owned National Transmission and Despatch Company (NTDC) transmits power to the DISCOs ((10 state-owned and 1 private). The Central Power Purchasing Agency (CPPA) buys power from generators on behalf of the DISCOs. K-Electric is the only vertically integrated, private company that has forayed into generating, transmission and distribution to the Karachi Metropolitan area. The Alternate Energy Development Board (AEDB) under the Ministry of Power has the role of promoting and implementing RE projects in the country. Overall, the generation, transmission and distribution segments continue to be highly regulated by the government.

The country's power sector has been characterised by insufficient generation (leading to frequent power cuts), lack of access to power in the rural areas and high technical and commercial losses. The transmission and distribution sector faces problems of circular debt, thereby constraining investments and power sector reforms. Owing to the circular debt problem, the CPPA is unable to recover the costs from DISCOs, thereby leading to a cascading deficit between cost of generation and recoverable tariffs from power consumers.

Pakistan's transmission and distribution losses are high and infrastructure is not ready to accommodate high in-firm RE generation. Furthermore, the country does not have an electricity market for power trading. A proposal is being prepared for the launch of a power market with bilateral contracting.

Sri Lanka

The Ministry of Power and Energy (MOPE) is responsible for formulating and implementing a national policy for power and energy of the country. It facilitates the development of projects in generation, transmission and distribution by ensuring efficient conduct of business and sound monitoring, investigating and planning of electricity facilities. PUCSL is empowered to regulate the electricity and petroleum industries. Under Sri Lanka Electricity Act No. 20 of 2009, PUCSL is the economic, safety and technical regulator of the electricity sector. SLSEA, which comes under the purview of Ministry of Power and Renewable Energy (MPRE) is the apex institution for policy formulation, promotion and conducting research for development of RE and indigenous energy sources. It also strives to improve energy efficiency through research and development and knowledge management.

Power generating entities in Sri Lanka can be broadly classified as (a) Ceylon Electricity Board (CEB): state-owned corporation engaged in power generation, transmission and distribution (four licences, catering across four distribution regions) of power; (b) IPPs: private power plants engaged in thermal power production; and (c) small power producers (SPPs): independent private power plants producing non-conventional renewable energy (hydro, solar, wind, biomass). CEB solely owns and operates the electricity transmission network of the country. There are five distribution licensees; four are controlled by CEB and one is privately managed - Lanka Electricity Company (LECO).

Private participation in the power sector is limited to the generation side and state-controlled CEB continues to be vertically integrated. There is absence of a holistic short-term power market and power exchanges are non-existent.

Although the country has prepared a RE policy to foster such projects, the electricity market has not yet evolved to complement RE injection. Transmission and distribution infrastructure weak and energy access is constrained. Privatisation in the power sector has been limited and technology adoption has been slow. A few power sector projects are being co-funded by development partner countries and bilateral and multilateral agencies, but lack of strong enabling policies and regulatory oversight hinders execution.

4.1.3 Implementation Issues

Challenges at the time of implementation can arise owing to various factors and the complexity of implementation increases as the capacity of variable RE generation increases. Implementation challenges that may be faced by the SAARC Member States are listed below:

1. **Dispersed connectivity**: As the wind and solar generation assets are deployed at regions with high primary resource availability, such assets, on many occasions, could be widely spread geographically. Also, the location of installations is often far from urban centres and, hence, telecommunication infrastructure is missing. This results in poor connectivity for data exchange and site to utility communications.

2. **Data disruptions**: Breaks in dynamic data collection and incorrect data mapping are a source of pain in forecast utilisation and accuracy accounting. They may also result in mismatches between utility systems that are not synchronised.

3. **Stakeholder participation**: As the capacity of variable RE increases, there may be a sharp increase in the number of entities required to participate in the process of forecasting and associated grid management activities. This results in coordination among a large number of parties, some of whom may not have the incentive to assign the requisite resources. Consequently, enforcement mechanisms or incentivisation structures are needed to ensure effective implementation of forecasting systems.

4.1.4 Technical Challenges

Implementation of wind and solar forecasting systems must be precluded by the enabling infrastructure in a country. The key technical requirements for establishing a forecasting system are detailed below:

1. **Infrastructure**: Forecasting of wind and solar power requires a detailed collection of static information on all generation assets. For effective collection of and utilisation of static information, a coordinated effort is needed to collect the information at source through a standardised framework. Additionally, a central repository of the information needs to be maintained and made available to all relevant stakeholders without discrepancies. All changes to the information should be updated without loss of consistency across organisations/ stakeholders.

Such a system requires IT infrastructure that is owned and maintained by a designated organisation/department.

Real-time access to and collection of dynamic data from all generation sites is also an important prerequisite for the monitoring and analysis of generation and the performance of forecasting systems. Dynamic data must also be accessible for utilisation in forecasting systems via standard data sharing protocols. The collection and storage of dynamic data requires SCADA infrastructure to be integrated with existing power system data. SCADA implementations are usually done as a matter of routine process, but the storage and easy access of this data for forecasting system implementation require additional infrastructure deployment.

2. **Meteorology**: Forecasting of wind and solar power requires meteorological inputs for effective implementation. The meteorological expertise needed to provide such inputs is not easily established. It requires a concerted effort at the national level driven by governmental impetus. Given the broad ranging implications of meteorology on a country, the foundation is already set up in all the SAARC Member States as detailed in Chapter 3. The challenge in meteorology is having dedicated services from the meteorological department catering to the forecasting of wind and solar power generation. An additional challenge is the multidisciplinary coordination needed between the meteorological and power departments/organisations of the country. This requires collaboration at a ministerial level to bring together the normally independent functioning of the meteorology and power divisions.

3. **Information technology**: The final layer in the implementation of forecasting systems is the IT system, which brings together the data from disparate sources and processes it for utilisation and consumption. Implementation of forecasting techniques also requires expertise in software development that can be developed in-house at the electricity grid management utilities or outsourced to other public or private organisations. Development of additional IT systems and knowhow for implementation of forecasting requires planning and consultations with stakeholders to ensure all requirements are mapped with sufficient detail. Data exchange and cybersecurity considerations must be accounted for, which may not be covered by the prowess of existing electric grid utilities at all SAARC nations.

Preparedness across SAARC Member States varies. Collection of static information from wind and solar generating assets is not strong in countries such as Afghanistan and Maldives. In Nepal and Bhutan, lack of ground weather systems to monitor transient weather changes hinder forecasting. Owing to lack of RE resources, IT infrastructure is also not present in most SAARC Member States.

4.2 Recommendations for Implementing Forecasting Techniques

General recommendations for the implementation of forecasting systems in SAARC Member States can be broadly classified into recommendations for planning, policy, meteorology and variable RE forecasting.

Planning and policy: At the initial stage of building capacity and solutions for forecasting of wind and solar power, it is critical to carry out a process of planning and policy analysis. The planning stage should cover the mapping of all wind and solar assets in the country and an initial collection of all available static data.

This may be followed by a benchmarking study for the country to get a better understanding of the feasibility of implementing different aspects of the forecasting system. A benchmarking study also allows for an understanding of the forecasting accuracies that may be expected over different time horizons. Finally, the benchmarking study would allow for decision-making on the error metrics that can be used for forecast assessment given the specifics of each country's grid management requirements. However, carrying out a benchmarking study over the entire portfolio of wind and solar generation assets in the country may be an expensive process depending on the penetration of wind and solar power generation. In such a scenario, benchmarking over a sample set of wind and solar sites is recommended. The sample set should cover both wind and solar sites with as much geographical diversity as possible in order to get a reasonably precise picture from the study. Policy decisions may also be driven by the benchmarking study, which will provide key inputs on expected accuracies for different time horizons and the efficacy of NWP in providing weather forecasts that meet the requirements of wind and solar power forecasting. It may lead to requirements for multiple sources of NWP data or just one.

At the time of planning for a forecasting system, the challenges that arise from IT and infrastructure requirements must also be taken into consideration. A standard set of compliance requirements should be created for data communication standards, data exchange protocols, hardware and software requirements that must be adhered to by an entity involved in the development of a forecasting system. In order to create a set of standards, consultations with relevant government departments is recommended to ensure cyber security and data protection is not compromised. It is also recommended to adopt open standards for interfacing with the utility IT systems that allow interoperability and easy switching between vendors if needed. Special care must be taken to prevent compliance requirement being conducive to vendor lock-in.

Finally, to reiterate, it is important to carry out a consultative process for policy decision-making. As multiple stakeholders are impacted by any policy decision, getting all views and giving due consideration is critical to the success of developing a forecasting system. Therefore, the responsibility of stakeholder consultations should be assigned to an independent body that is free from bias. It is also recommended to make all transcripts of the consultation process open to public access and open to comments from all stakeholders.

Assigning responsibility and ownership of the forecasting process is recommended in a distributed manner such that both generators and utilities take ownership of the forecasting process. By engaging both grid management and grid connected stakeholders, the efficacy of the forecasting process can be greatly enhanced as aggregated level forecasting views will be covered by the utilities, while the vagaries of site level forecasts will be covered by generator participation in the forecasting frameworks.

Meteorology

Every SAARC member state has its own dedicated meteorological department. However, the different departments are at various stages of advancement. Most meteorological departments are focussed on the predictions of extreme events and on weather forecasts that have the greatest impact, such as weather forecasts for aviation, agricultural activities or for marine activities. Growth of renewables is relatively recent on the timelines of the meteorological departments' development. As a consequence, there is little or no dedicated focus on weather forecasting for the purposes of RE integration the SAARC nations.

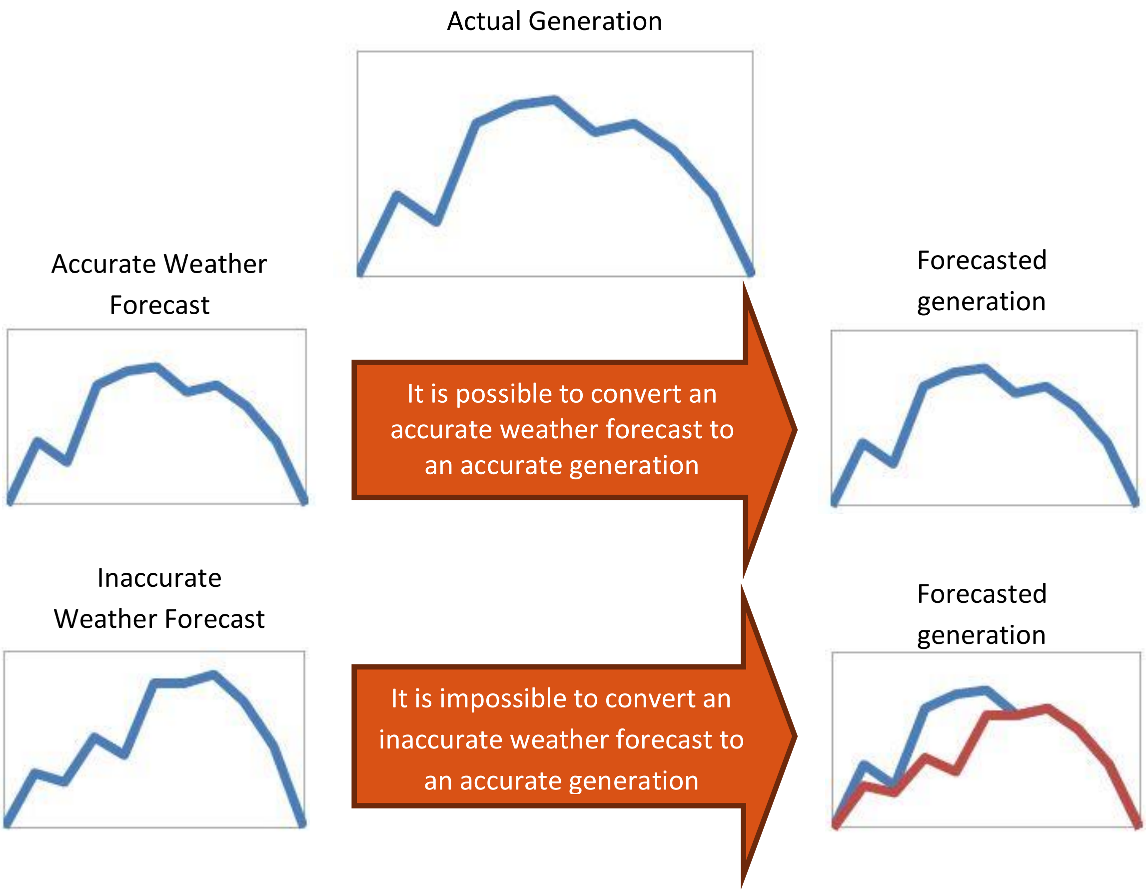

Figure 15: Without Accurate Weather Forecast, a Generator Cannot Submit Accurate Schedules

Globally, different forecasting methods are being used to predict weather variations. Each of the different weather forecasting techniques have their advantages and pitfalls.

Table 29: Details of Forecasting Methods Used Globally

Parameters	NWP based forecasting	Satellite based forecasting	Total sky imager	Statistical approaches
Refresh Rate	6-24 hours	0.5-24 hours	<1 minute	0.5-2 hours
Forecast's temporal resolution	1-6 hours	Minutes	Minutes	<15 minutes
Forecast's spatial resolution	4-120 sq. km	>1 sq. km	Local surroundings	<1 sq. km
Best forecast accuracy achieved	>6 hours ahead	1-6 hours ahead	<0.5 hour ahead	Short term
RMSE (local, hour ahead)	Very high	20-25%	Not available	N/A
RMSE (large grid, day ahead	20-60%	~5%	No long-term forecast	N/A

In majority of the SAARC Member States, NWP systems and models are being used to predict weather variations. Countries can also use the services from some of the global NWP models available in the SAARC region.

Table 30: Good NWP Models Available for the SAARC Region

Model	Agency	Resolution	Horizon	Updates
High resolution global model (HRES)	European Center for Medium Range Weather Forecast (ECMWF)	9x9 Km	240 hours	2/ day
Icosahedral Non hydrostatic model (ICON)	Deutscher Wetterdienst (DWD)	13x13km	180 hours	4/ day
Global deterministic prediction system (GDPS)	Canadian government meteorological department	23x26km	240 hours	2/ day
Global forecast system (GFS)	National Ocean atmospheric administration (NOAA)	48x55km	180 hours	4/ day

However, these models are not accurate for small regions over short time scales of under a few hours. These models perform poorly in 15-minute timescales.

In view of this, an objective for the meteorological departments to develop their own NWP products to serve the power sector is recommended. This will be beneficial to not only the integration of renewables, but also better forecasting of electrical demand and thereby better demand-supply mapping capabilities of the electricity utilities.

It is also recommended to create avenues for collaboration between the electric grid utilities and the meteorological departments that may be siloed from each other. Regular interactions between the two departments promoted by an independent governmental body would be beneficial for multiple electric grid management activities. For countries with significant run of the river hydro generation capacities, such collaboration may already exist and can be expanded to cover the integration of wind and solar power as well.

Wind and solar forecasting

For setting up forecasting for wind and solar power generation, apart from the inputs from meteorology, consideration must also be given to the operational requirements of grid management. Further, if market mechanisms involving wind and solar power generation are also of importance to the country’s plans, market requirements must be taken into consideration for setting up the forecasting system.

The following factors should be considered:

- Time horizon of forecasts

- Temporal resolution of forecasts
- Requirement for deterministic forecasts
- Requirement for probabilistic forecasts (uncertainty planning)
- Expected error range of forecasts (driven by benchmarking study) for all horizons
  - Requirements for wind and solar may differ depending on the region
  - Ramp forecasting requirements may be taken into account independently of the requirements for general wind and solar forecasting
- Reporting and visualisation requirements
- Operations support requirements (RTC support / working hours support)
- Staff training requirements

Based on the requirements gathered on the points above, a detailed documentation of requirements may be drafted for use for the development and implementation of the forecasting system.

After finalisation of requirements, a pilot project is recommended for forecasting of wind and solar power with forecast service provider(s). Pilot projects may prove highly useful in the decision-making process on the requirements of a forecasting system. It is also recommended to perform a pilot with multiple vendors such that no inherent biases enter into the decision-making process and a broader review of forecast performance is enabled. While carrying out the forecast pilot and in final implementation, choose more than one forecast service provider with forecasts that are not highly correlated to each other. Such an approach allows for higher accuracy in forecasts as explained in the section on forecasting techniques.

Further, an additional infrastructure requirement may be placed at the sites of generation for meteorological observation systems. While it is common practice for developers to install such systems, sharing of the data collected may not always be part of the agreement between the generators and grid operators. For better understanding of weather phenomena, higher accuracies in forecasting and increased capability of grid operators, include installation of local sensing systems for weather as part of the requirements. Modes and requirements for data sharing from such systems must also be covered as part of the requirements setting process.

Specific to solar forecasting is the usage of additional technology to capture cloud movement-influenced variability in generation. If there exists largely solar capacity in a region with little wind generation, it may become necessary for grid operators to place higher accuracy requirements for the very short to short term such that imbalances can be managed effectively. In such a scenario, it is recommended that the requirements for installation of sky imaging systems are covered in the scope of generators or forecast service providers and accounted for in the pricing terms.

Based on the requirements gathered on the points above, a detailed documentation of requirements may be drafted for use to develop and implement the forecasting system.

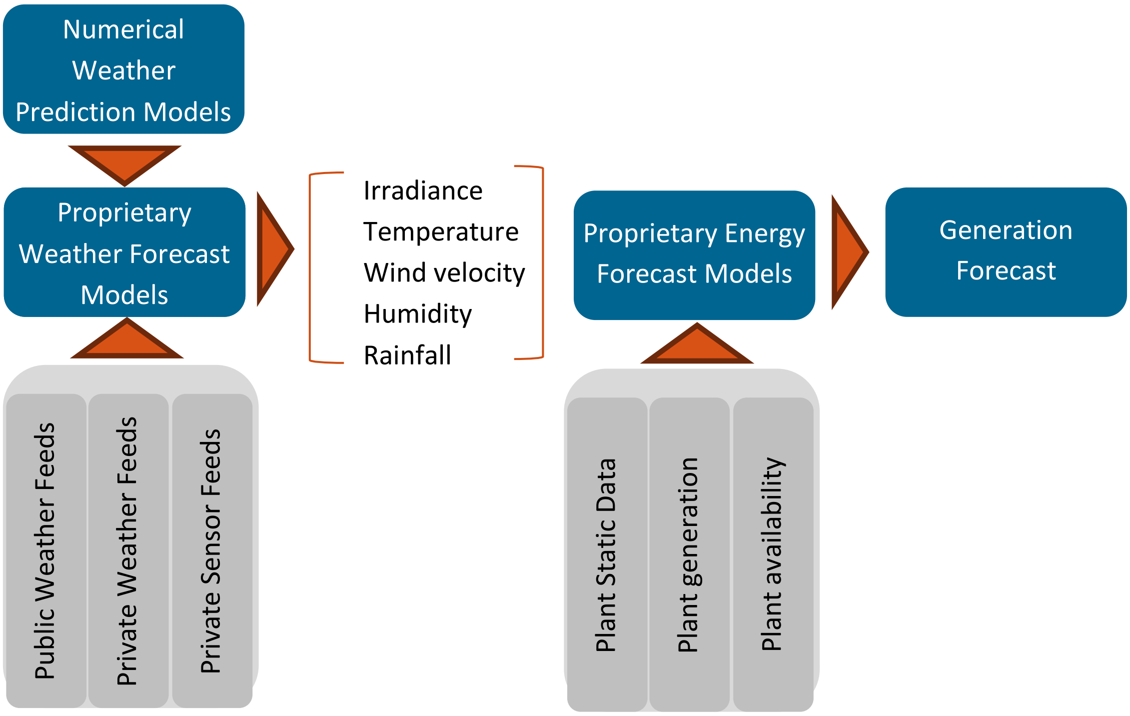

Figure 16: Recommended Forecasting Methodology for Day-Ahead Scheduling

Designing a PV Power Forecasting System

PV power prediction typically involves the following model chain:

- Forecast of site-specific global horizontal irradiance (GHI)
- Forecast of solar irradiance on the module plane
- Forecast of PV power
- Regional forecasts need an additional step for up-scaling.
- Forecast of regional power production

The steps may use physical or statistical models or a combination of both. The GHI data can be predicted using different input data and models. For short time scale forecasting, on-site measured irradiance data along with time series models can be used. For medium term forecasts (for up to 6 hours ahead), forecasts based on satellite images can be relied upon. For sub-hourly timescale cloud information from ground mounted sky imagers can be used to derive irradiance forecasts. NWP based irradiance forecasts can also be used for predictions beyond 4-6 hours ahead. Post processing of NWP model output can correct for systematic deviations and bias correction based on statistical analyses. Finally, solar PV predicted from select sites can be up scaled to a particular control area.

Specifying a forecast accuracy is essential towards building a strong solar forecast system. To assess solar forecast accuracy, actual data can be compared with corresponding model measurements of solar irradiance. After evaluating the statistical error measures (through metrics like RMSE, MAE etc.), decisions and judgements can be made accordingly. The probability distribution function of forecast errors or power predictions will give insights into uncertainty information of the model.

Additionally, it is important to undertake ramp forecasting and variability forecasting. In SAARC Member States where installations are small and well-distributed, a smooth RE power feed can be expected. However, as solar and wind farms are installed in clusters, a larger probability of ramps emanates. RE power can suddenly increase or decrease. In that case, hourly predictions will not be sufficient to deal with ramps. Two main methodologies of ramp and uncertainly forecasting has been established, based on case studies from the developed markets. They are statistical approaches working on single NWP forecasts and uncertainties derived from ensembles of predictions. Developed RE markets in the SAARC region like India can look towards adopting such ramp forecasting models. As an appropriate tool for online assessment, appropriate forecast uncertainty confidence intervals can also be introduced.

Designing a Wind Power Forecasting System

The designing of a wind power forecasting system also begins with meteorological data. Globally, wind power forecast models can be divided into physical or statistical types. Most operational forecast systems apply a combination of statistical and physical models by using the best of both worlds. Typically, the output from weather prediction models like NWP is fed as input to wind speed forecasting models. Globally, there are several wind power software models whose services can be used by the SAARC Member States for short term prediction models.

Table 31: Wind Power Software Models with International Operation

Model Name	Developer(s), Operating company	Method
Prediktor	L. Landberg, DTU Risø, Denmark	Physical
WPPT	Eltra/Elsam collaboration with Informatics and Mathematical Modeling at DanmarksTekniskeUniversitet (DTU), now: ENFOR, Denmark	Statistical
Zephyr	Risø& IMM ay DTU, Denmark	Hybrid
Previento	Oldenburg University / energy & meteo systems GmbH, Germany	Hybrid
eWind	True Wind Inc., AWS Truepower, USA	Hybrid
Sipreólico	University Carlos III, Madrid, Spain & Red Eléctrica de Espana	Statistical
WPMS	Institut für Solare Energieversorgungstechnik (ISET), now Fraunhofer IWES, Germany	Statistical
WEPROG / MSEPS	J. Jørgensen& C. Möhrlen at University College Cork	Hybrid
GH Forecaster	Garrad Hassan	Statistical
AWPPS	École des Mines, Paris	Statistical

Model Name	Developer(s), Operating company	Method
LocalPred& RegioPred	M. Perez at Centro Nacional de EnergiasRenovables (CENER) and Centro de InvestigacionesEnergéticas, Medioambientales y Tecnalógicas, Spain (CIEMET)	Hybrid
Alea Wind	Aleasoft at the UniversitatPolytécnica de Catalunya, Spain (UPC)	Statistical
SOWIE	Eurowind GmbH, Germany	Physical
EPREV	Instituto de Engenharia de Sistemas e Computadores do Porto (INESC), Instituto de EngenhariaMecânica e Gestão Industrial (INEGI) and Centro de Estudos de EnergiaEólica e EscoamentosAtmosféricos (CEsA) in Portugal	Statistical
EPREV	Aeolis Forecasting Services, Netherlands	Hybrid

In most cases, forecast data captured from some wind farms/ turbines will be required to be up scaled to derive a total regional production. After looking at the spatial correlation between wind power generations and forecasting errors, the uncorrelated error can be reduced through spatial smoothing. Ramp and uncertainty forecasting also needs to be incorporated in the same way as discussed for solar forecasting system.

Guidelines for establishing the forecasting system

The following table provides a step-wise approach for establishing a forecasting system. The points given in the table may be applied to all SAARC Member States as a general technical guideline. Coupled with the self-evaluation framework provided in the earlier section, these points intend to serve as a broad technical guide that stakeholders from every country may use to identify the stage of their development and its respective requirements.

The guidelines are structured into the aspects that need to be considered and completed for setting up a forecasting system.

Table 32: Guidelines for Setting up A Wind and Solar Forecasting System in SAARC Member States

Aspect	Guidelines
Planning	• Technical decisions on horizons of forecasting, temporal resolutions and frequency of forecast updates • Technical decisions on requirement for deterministic or probabilistic forecasts • Technical decision on number of forecast service providers (FSP) to be engaged in system • Decision on new installations or upgradation of SCADA systems connected to wind and solar generators • Decision on sizing of IT infrastructure based on the technical parameters considered in previous points

Aspect	Guidelines
	• Decision on technical support expectations/requirements • Framing of contract or tendering terms for required infrastructure, IT hardware and software
Infrastructure	• Vendor selection for installation/ upgradation of SCADA system if deemed necessary • Vendor selection for IT infrastructure purchase and commissioning • Vendor selection for system software development and installation • Decision on requirement for installation of meteorological observation systems at generator sites • Decision on installation of sky-imaging systems at solar generation sites
Implementation	• Benchmarking studies on forecasting of wind and solar power • Decision on standard error metrics for assessment of forecasts • Decision on assigning responsibility of forecasting on generators or grid operator or other utility/national institution or all • Pilot project with FSPs • Decision on selection of FSPs • Trial runs of forecast system with all stakeholder participation
Operation	• Decisions on assigning responsibility of managing forecasting system with existing or new team structures at the grid operation utilities • Inclusion of generator downtime disclosure into forecasting system on a real-time basis • Utilisation of forecasts at all time horizons into dispatch schedule planning and management • Monitoring and reporting of the imbalance impacts before and after implementation of forecasting system • Review of forecast performance regularly

It is important to note that the techniques (models) adopted for forecasting wind and solar power are of secondary importance for development of a forecasting system. The ground work for establishing a foundation that allows for multiple forecasting methods to be applied and demonstrated is of primary concern. It is usual practice to adopt multiple methods of forecasting for both wind and solar.

RE forecasting can be done at a centralized or decentralized level, global best practices show that centralized forecasting is the best practice approach for economic dispatch. It provides greater consistency in results due to the application of a single methodology. Furthermore, there is Lower uncertainty due to the system operator's ability to aggregate uncertainty across all generators.

Country-specific recommendations for the implementation of forecasting systems are presented in the sections below. Each country is at a different maturity level in terms of variable RE deployment and forecasting readiness. Drawing on the current status of each country from the earlier sections, focussed recommendations are provided covering aspects related to forecasting techniques and their associated prerequisites.

4.2.1 Afghanistan

Zonal Renewable Energy Centres under the National Renewable Energy Policy of Afghanistan can be set up for advancing the forecasting of wind and solar power in the country. In early stages, long- and medium-term forecasting of wind and solar power by the zonal centres in collaboration with the Afghanistan Meteorological Department (AMD) is recommended. This will allow the utilities to understand the potential for wind and solar power integration into the grid and prepare planning and policy outcomes accordingly. Mandating RE generators to report daily or weekly operational reports with ZRECs will allow for setting the ground for future implementations of a forecasting system. Specific recommendations are as follows:

Meteorology - Capacity development programmes, such as staff training through international MoUs are already underway at the AMD, which will provide a foundation for development of the meteorological department. Similar to other nations, it is recommended that AMD be engaged by the Da Afghanistan Breshna Sherkat (DABS) at early stages so that progress in meteorology is guided by the requirements of the power sector in addition to the rest of their objectives.

Forecasting methods - Given the low penetration of wind and solar power in the country, statistical models deployed for forecasting of wind and solar power have limited applications as the data requirement will not be met. In such a scenario, physical models for forecasting for the medium- and long-term horizons can be developed. Short-term horizon forecasting will have little benefit in the absence of a real-time data exchange system and other infrastructure.

4.2.2 Bangladesh

Bangladesh has relatively limited scope for growth in wind and solar power capacities, as discussed earlier. The need for developing an advanced forecasting system within the country is also limited. The Sustainable and Renewable Energy Development Authority (SREDA) can serve as an ideal entity for carrying out a benchmarking study and consultation activities related to forecasting system development. Given that there is already a provision for variable RE generators to submit hourly resolution forecasts, the scope of forecasting can be added by increasing the responsibility of the generators for forecasting. Alternatively, the forecasting of the complete capacity may be carried out centrally by SREDA or Power Grid Company of Bangladesh (PGCB). As the total capacity is relatively small, it is recommended that the forecasting activities be carried out centrally by SREDA or PGCB as the process of creating and utilising forecasts can be better managed for a small capacity if it is not distributed. This will also allow the central utilities to build capacity internally, which will help in aspects of planning and policy development as well.

Meteorology - The Bangladesh Meteorology Department (BMD) currently has sufficient weather data available at its disposal to meet the needs of wind and solar forecasting with some added efforts towards customisation. BMD is focussed on dissemination of data catering to extreme weather conditions. It is recommended to engage BMD for the purposes of catering to power system operation including wind and solar power integration. High level engagement between SREDA, PGCB and BMD for providing NWP data to power sector stakeholders via a standardised data sharing framework may be achieved with nominal additional resources.

Forecasting methods - As the country is exposed to extreme weather conditions, generation of wind and solar power will also have periods of high variability. This can be accounted for using short- and medium-term forecasting, which may be done using physical and statistical models. In order to fully understand the impact of variability, uncertainty planning is needed. However, given the lower penetration of wind and solar, and the relatively higher resources needed for uncertainty forecasting, deterministic forecasting in the country at current penetration levels is recommended.

4.2.3 Bhutan

High levels of hydro power generation capacity and very low levels of wind and solar power generation exclude the need for forecasting of wind and solar power in Bhutan. Hydro power generation is an easily dispatchable resource, which may be used to cover for any variability arising from wind and solar power generation at a small scale. Further, some forecasting activities are already being carried out by the country.

Meteorology – Short-term forecasting requirements of wind and solar power forecasting can be met by the National Centre for Hydrology and Meteorology (NCHM). NCHM in collaboration with the power departments may engage an external consulting agency in order to estimate the scope for additional RE implementation in the country considering the use of hydro generation as a balancing power supply. This can be clubbed with the benchmarking of wind and solar forecasting in the country in order to arrive at a reasonable estimate of maximum potential RE capacity addition in the country without the need for additional balancing power investments.

Long-term forecasting capabilities - Possibilities of engagement with the meteorological departments of neighbouring nations can be explored to expand capabilities of forecasting for medium- to long-term horizons as well.

Forecasting methods - Similar to Nepal, Druk Green Power Corporation Ltd (DGPC) and Bhutan Power Corporation (BPC) are recommended to avail long-term forecasting of off-grid variable RE generation to help with planning and policy activities.

4.2.4 India

Given India's advanced stage of forecasting wind and solar power, the recommendations revolve around improving forecasting systems rather than implementation. The fundamental requirements for forecasting systems of infrastructure, meteorology and IT are already in place. Regulatory consideration to reduce the time of applicability of forecasts as per the 'Forecasting and Scheduling' regulations may be considered; as with the implementation of REMCs, communications for the purpose of RE scheduling between the state, regional and national centres are streamlined. This may reduce the time overhead in relaying the changes in generation scenario which could be used to close the gap in reporting leading to higher accuracies. For further development of forecasting, the following may be considered:

Meteorology - The already significant base in meteorological output of the Indian Meteorological Department (IMD) can be better leveraged through dissemination of its weather forecasting products.

Currently, IMD is using state-of-the-art Climate Forecast System model developed by the US' National Centres for Environmental Prediction (NCEP). But its forecast capacity is still weak and it is used only to supplement the operational statistical forecast. Indian scientists try to improve its predictive accuracy by simulating temperature-related oceanic phenomena such as Equatorial Indian Ocean

Oscillation (EQUINOO) and Indian Ocean Dipole (IOD). Apart from IMD, several domestic and foreign research institutes like issue Long Range Forecast (LRF). In general, the NWP systems of leading global NWP centres are improving by 1 day of predictive skill per decade. India can improve its NWP systems through several interventions including:

- Improvements in model dynamics and physics
- Better observations
- Careful use of forecast and observations, allowing for their information content and errors – achieved by variational assimilation e.g., of satellite radiances
- Four-Dimensional Data Assimilation
- Hybrid ensemble

Additionally, the current scope of collaboration between the IMD and the electric grid utilities may be expanded to include regular provisions of weather forecasts to all the utilities via a standardised data sharing platform. Such data may also be made available to the private sector enterprises commercially for increased utilisation.

Forecasting methods - REMCs and the forecasting and scheduling regulations in the country provide comprehensive forecast data to the stakeholders. However, all forecasts are deterministic and there is a gap in uncertainty planning that can be met through ensemble forecasting. Weather forecast ensembles and probabilistic power forecast ensembles can provide quantification of uncertainties in wind and solar power forecasts. The use of such ensembles can allow for better planning and utilisation of reserve capacities.

4.2.5 Maldives

Maldives has very limited penetration of solar power generation. Growth in solar power generation may be driven by rooftop installations which present a different challenge. In such a scenario, State Electricity Company Ltd (STELCO) is recommended to establish an easy-to-use framework for rooftop solar systems to be registered with it. This will promote growth in this segment to be captured adequately in STELCO's planning and operations activities.

Meteorology - The Maldives Meteorological Service (MMS) is not sufficiently resourced for immediate distribution of weather forecast data relevant to the forecasting of wind and solar power. The ongoing experimental deployment of a regional weather model presents an opportunity for developing capability to serve the power sector. Engagement between STELCO and MMS for data sharing could prove beneficial to both organisations, as NWP data may be used by STELCO and observational weather data from any solar generation plants may be shared with MMS for further utilisation in weather services.

Forecasting methods - STELCO is advised to carry out the short- and medium-term forecasting of aggregated rooftop solar generation. This will allow better forecasting of the electrical demand profiles of the country as the demand for grid power will be affected by rooftop generation. Hybrid models for aggregated rooftop solar generation forecasting may be used.

4.2.6 Nepal

Forecasting of wind and solar power in Nepal is not an activity that is needed for grid operation or market mechanisms given very low penetrations. Focus on variable renewables if on-off grid systems that do not require forecasting for operation. Given this scenario, no immediate recommendations on forecasting of wind and solar power are required. However, as the share of off-grid renewable generation increases, it would be beneficial to the utilities to keep track of their exact share. With this in mind, Nepal Electricity Authority (NEA) is recommended to create an easy-to-use framework for off-grid systems to be registered with them. A basic incentive mechanism may be developed to encourage registrations and a standardised information form may be used to collect relevant information at the time of registration. With this, planning and policy activities of the NEA can be significantly benefited.

Meteorology - The Meteorological Forecasting Division (MFD), Department of Hydrology and Meteorology, has sufficient capability to provide NWP data for the purposes of wind and solar forecasting and grid management activities. The MFD may be engaged by the NEA for additional data sharing relevant to wind and solar forecasting.

Forecasting methods - Planning activities of the NEA can be augmented by carrying out aggregated forecasts of all off-grid and grid connected wind and solar generation. Forecasts of medium- to long-term horizons through the use of physical methods are recommended for planning activities.

4.2.7 Pakistan

Pakistan is in early stages of building wind and solar power capacity. However, the formation of the Alternative Energy Development Board (AEDB) offers a key channel through which the development of a forecasting system may be driven successfully. The consultative process for the policy and planning initiatives may be carried out effectively by the AEDB. In addition, Pakistan is well positioned to carry out initial assessment and benchmarking studies on wind and solar forecasting through AEDB. The following technical recommendations may be considered while implementation:

Meteorology - The Pakistan Meteorological Department (PMD) has sufficient expertise to serve the needs of wind and solar power forecasting. In order to better leverage the PMD's resources, it is recommended to engage the PMD from a power systems point of view and build products that serve the sector through efforts such as modelling at a finer temporal resolution of 15 minutes to 1 hour. Further, an engagement of the PMD by AEDB towards a higher engagement level is recommended. A MoU between the two departments may serve as an initiating conduit for engagement. Observational weather data collected from wind and solar sites may also be shared with PMD, which would be useful for its evaluation and weather modelling.

Forecasting methods - Given the relatively advanced meteorological capabilities of the PMD, physical models can be readily implemented. Statistical model deployment is also immediately feasible for the existing wind and solar capacities that have historical datasets that can be utilised towards accuracy improvements. As the NTDC Grid Code does not provide a specific scheduling process for wind and solar, they are at risk of curtailment due to variability. Forecasting horizons of hours ahead to day-ahead are recommended for focus for higher power injection.

Long-term horizons extending up to a few months ahead will serve the Central Power Purchasing Agency (CPPA) in developing a competitive power market. Forecasting for this horizon is not yet foreseen to be a recurring requirement in Pakistan, but a short-term requirement for planning purposes.

4.2.8 Sri Lanka

Growth of wind and solar power generation in Sri Lanka is expected to happen at an increasing pace until conventional generation is phased out completely. This makes the need for establishing a comprehensive forecasting system a core part of the electricity grid development process. The first and most important recommendation would be to develop data telemetry networks covering 100% of the wind and solar capacities in the country. As it stands, only larger capacity plants have been covered by SCADA networks (as per primary research surveys). As smaller capacity plants have been given a blanket approval, they are likely to be outside the scope of monitoring from a grid perspective. With increased numbers of smaller plants, the aggregate capacity of such plants may be significant enough to have impacts on grid stability and will require management which will not be possible without visibility over their generation patterns. With mandated real-time telemetry for all grid-connected plants over 1 MW capacity, the aggregate generation of all small plants can be forecasted and managed effectively. Existing provisions cover forecasting to some degree under the Ceylon Electricity Board's (CEB) existing responsibilities. It is recommended to establish a dedicated variable renewable focussed unit at the CEB to manage the growing injection of wind and solar power into the grid in collaboration with the other grid operation teams. Through a dedicated unit, the monitoring and management of wind and solar power can be carried out more efficiently and the process of communications with the generators for operational activities can be more streamlined. It is also recommended that a benchmarking study be carried out in the country, which can be taken up by SLSEA as the nodal agency. Sri Lanka, at its current stage, is in an appropriate position to carry out the planning and policy related activities for the establishment of a comprehensive forecasting system in the country.

Meteorology - The Department of Meteorology (DoM) of Sri Lanka is focussed on weather forecast for agriculture, fishing activities and flood warnings. The DoM's capabilities are sufficient to cater to the requirements of wind and solar power forecasting with little additional efforts. SLEA and CEB are recommended to engage the DoM for meeting the requirements of wind and solar power forecasting as well as electrical demand forecasting.

Forecasting methods - Given the larger penetration of wind and solar power in the country, the impact of variability on the electric grid is also expected to be significant. Consequently, to achieve the ambitious targets of 100% RE generation in the country, deterministic forecasts alone will not be sufficient. Uncertainty planning through ensemble forecasting should be established for the short and medium terms in addition to the deterministic forecasting already being carried out. Forecasting at horizons of up to 7 days ahead can also be established, if not already in place. Hybrid methods are needed to be deployed to achieve accuracies sufficient for grid management activities.

4.3 Requirements for Implementation of Recommended Forecasting Techniques

Forecasting is the first step towards building a robust RE ecosystem. Globally, developed countries have implemented RE via forecasting, demand response, flexible generation, and system balancing. However, wind or solar projection without addressing policy, technical, and economic challenges (or uncertainties) could have negative consequences on a country's power system. Hence, cost of system integration (transmission system planning and ancillary market development), development of the power market, and management of demand and supply (flexibility options on demand and supply sides, and adding storage to the grid) are crucial.

This section will assess the technical, policy and socio-economic implications, and interventions to carry out the recommendations discussed in the previous section.

4.3.1 Policy-level Solutions

Policy and regulatory support is important for developing wind and solar forecasting scenarios in SAARC Member States. Strong RE policies and enabling frameworks are required in countries that lack RE generation, such as Afghanistan, Bangladesh, Bhutan, Nepal, and Maldives.

While policy support on wind and solar forecasting has been discussed in Section 3.3, policy solutions pertaining to improvement of the RE market has been discussed in Section 4.1.1.

4.3.2 Financial Requirements

Implementing a forecasting system entails cost for stakeholders. Grid operators need to spend on building or strengthening existing infrastructure for meteorological data, and generators need to spend on improving data availability.

The initial cost of installing a forecasting system can be high, especially if it requires upgrades or investments in hardware (SCADA systems, servers, and communication equipment), and setting up of physical infrastructure, such as control centres. The cost of developing software specific to the requirements of a country can also be significant. Operating costs, though, tend to be lower.

In terms of implementation of the forecasting techniques themselves, there is a heavy dependence on the approach adopted by any country. Development and implementation of forecasting methods is a knowledge based and information technology driven activity which relies on weather inputs. As such, the cost of the weather inputs and the costs of personnel involved in development and implementation constitute the full costs of forecasting methods implementation. The costs of personnel and weather inputs may be within a wide range as the approach may vary from appointing one or forecasting agencies by negotiating service costs inclusive of weather forecasts and power forecasts or building in-house capacity to generate forecasts by building a team dedicated towards forecasting and management of forecasts. The approach towards building capacity again has varying costs associated with it depending on the availability of skilled labour and the prevailing labour market costs. As a consequence of such variability between approaches adopted and the specificities of each country's circumstances, attempting to quantify costs associated with forecasting techniques themselves may be deemed inappropriate. However, these costs exclude the costs of the system level requirements for a forecasting system which are discussed below.

The following are the cost components that will be incurred in setting up a forecasting system, categorised into one-time and recurring costs:

One-time costs

- Engagement of consultant for:
  - Stakeholder consultations and policy framing
  - Evaluation of system requirements, and framing request for information and request for proposal documents

- SCADA infrastructure set-up / upgrade
- IT Infrastructure set-up / upgrade
- Analysis, reporting and decision support software for grid operators
- Integration of new/upgraded hardware and software with existing systems

Recurring costs

- Licences for IT infrastructure, especially software components
- Weather service providers' service fees
- Forecast service providers' service fees
- Training of personnel at grid operation utilities and generator control centres
- Maintenance of SCADA systems

These costs are likely to be spread across multiple stakeholders, primarily grid operation utilities and generators.

A significant initial financial challenge faced in the implementation of a forecasting system is that while all stakeholders will incur costs, the benefit of improved grid operations are socialised over a large system, with no single stakeholder as a clear beneficiary.

Policymakers will have to design forecasting policies keeping this in mind. A possible approach to overcoming the financial challenges is that the initial cost of installing a forecasting system is incurred by a national government agency, e.g. national grid operator or transco, potentially also funded by a multilateral agency, such as the World Bank or the Asian Development Bank.

The operating costs for such a system could be recovered from the wind and solar generators, either as fixed cost per MW for providing connection to the grid, or as charges for causing system imbalance through an appropriate regulatory mechanism.

It is, however, critical for generators to ensure that the costs incurred because of forecasting requirements are accounted for at the time of investment. Competitive investment landscapes promote low-margin investments into wind and solar generation, which could be put under undue pressure through forecasting costs, unless well-planned.

Cost optimisation

With significant variation that may be seen between requirements of different countries, the costs involved will also vary considerably however, avenues exist for optimisation of costs with development in technology. Also, one-time costs are likely to outweigh recurring costs.

One important avenue for cost optimisation can come from a shift from physical IT infrastructure to virtual infrastructure. Security concerns usually drive decisions for IT hardware to be installed at the utility's premises, with limited external access. However, cloud-based infrastructure, with dedicated networking and advanced security protocols around data protection and access to systems, are a relatively new advancement that may be considered at the planning stage.

4.3.3 Socio-Economic Solutions

This section discusses the socio-economic benefits that can be reaped by each SAARC member state with the development of power markets and improvement of RE forecasting systems. As majority of the countries lack RE penetration, the socio-economic importance of RE adoption has been assessed, and possible roadmap for developing it discussed.

Afghanistan

The country has been under economic stress owing to decades of war and political unrest. Economic development has not been equitable, and a large part of the population still does not have access to social and economic reforms.

The country has majorly relied on donor funding to meet the government's expenses, and also to undertake social intervention projects, including in the energy sector. However, this is not sustainable in the long term, especially when it comes to the development of an RE ecosystem in the country. With less than 50% of the country's population having access to the electricity grid, setting up of an RE forecasting system is not a priority for the government. As a first step towards development of a strong electricity system, several multilateral organisations have been assisting the country in geospatial energy planning, power generation planning, as well as evaluating the country's techno-economic feasibility of RE systems.

In order to attract investments in the RE forecasting space, Afghanistan needs to develop the national grid, improve interconnection systems, and invest in RE generation facilities. As a start, the country can undertake a cluster approach model in a province with high RE potential, and set up RE plants in the cluster. The RE generation from the cluster can be complemented by baseload generation (majorly from diesel) to help generate stable, round-the-clock power. Because of weak transmission and distribution systems, the power generated in the province can be consumed within the province to avoid system imbalances and grid non-resiliency. Local ground-weather stations can be set up in the province (selected for cluster development) to provide accurate weather data. Furthermore, utilising global weather systems and collaborating with global technical partners, grid integration of RE along with dispatch scheduling and forecasting can be adopted.

While the overall investment is initially high, and may not align with the policy priorities of the government, long-term economic benefits cannot be discounted. The cluster-based approach, with its clean and reliable power supply, can precipitate large-scale economic and social development in the province. Industrial and commercial activity can also receive a boost, backed by reliable access to electricity. This can lead to scaling up and further augmentation of the power systems, adding RE generation along the way and improving the transmission infrastructure subsequently.

The economic benefits reaped from the cluster-based approach can be replicated in adjacent provinces having good solar and wind potential. This scalable model for economic development will reap social benefits as well.

However, the country's economy is weak, and there is lack of access to funds. In order to help the country tide over the crisis, Afghanistan National Peace and Development Framework (APNDF) was constituted. ANPDF is Afghanistan's plan to achieve self-reliance and increase the welfare of the population by building a productive and broad-based economy that creates jobs. Under this plan, donors had pledged $15.2 billion to support Afghanistan until 2020, and are further ironing out the next five-year framework (2020 to 2025). And while it intends to improve the fragile economy through creation of jobs and development of livelihoods, and ensure safety and security, economic activity cannot be spurred without reliable power supply. Also, with the country relying considerably on imported power and costly diesel, there is considerable scope of improving the supply mix, along with arresting foreign exchange outflow.

The strategy of the government, going forward, could be to look at a nodal-based development, backed by renewables, to generate industrial and commercial demand, and create employment for the rural population. This will improve living standards whereas the government will benefit from increased tax receipts. This will kick-start a ripple effect on the overall economy, leading to improved domestic revenue while reducing dependence on donor receipts.

Bangladesh

The country is looking to shift from an agro-based economy to an industry-based economy. However, economic strides cannot improve the country's overall well-being without addressing the socio-economic challenges.

Bangladesh is the eighth-most populous country, while ranking 92nd in terms of land mass. Hence, majority of the habitable areas are densely populated, diminishing access to food, housing, healthcare, sanitation, education, and employment. This has also led to a reduction in labour productivity. Also, majority of the workforce is employed in low-skilled jobs, thereby having negligible contribution to economic development. This has stalled innovation as the country struggles to transition to high value-added industries and products.

Reliable access to clean power can, to a large extent, reverse the negative impacts. Big cities such as Dhaka and Chittagong continue to experience 2-3 hours of power outages every day, while rural areas are worse off. Several rural villages have been setting up rooftop solar PV installations to tide over the power crisis. Ageing and restructuring of power plants and gas shortages have curtailed power supplies, especially during peak demand. Peak power demand is also unreliable, partly due to the country's vulnerability to climate change, such as hotter summers and prolonged monsoons.

Solar and wind generation can add to the baseload capacity of the country, and also act a substitute to natural gas-based generation and rising power imports from India. The plants can be set up in areas where land is not arable for agriculture. The RE plants can boost power generation to the grid and improve supply reliability in rural areas. A few community-based small solar plants have been set up by private companies, which are powering adjoining villages. This cluster approach can be replicated to other areas having similar opportunities. However, there is not much government support to scale this up.

Access to electricity will enhance income and employment opportunities in the country, especially in rural areas. For the semi-urban and urban areas, commercial and industrial activity can flourish without relying on costly diesel generators, which is lowering business productivity. The indirect benefit of electrification and grid electricity can be realised by improving the standards of education, health and social safety. This will further encourage economic growth, poverty reduction and human development.

The socio-economic implications can be far-reaching, with good and clean power supplies. With the rise in renewables, changing generation mix, increasing customer demand, and improved operational efficiencies, competition can be fostered on the power supply side, which can lead to the development of a power market. Efficiency-driven decrease in power cost will allow consumers to reap the benefits from lower power tariffs.

Forecasting of wind and solar will play a major role in this. Strong forecasting systems will allow improved grid integration of renewables, allowing suppliers and buyers to sell and purchase power at competitive rates. Energy-intensive industries will have the provision to purchase power at cheaper rates. This will improve the overall power ecosystem, whereas small industries can be set up in rural areas, thereby accruing employment benefits, and improving production and efficiency measures.

Bhutan

Popularly known as the land of Gross National Happiness, Bhutan's government has invested in improving the social wellbeing of the population and fostering sustainable development. According to the Bhutan Development Report 2019, the country has eradicated extreme poverty, with the national poverty rate declining from 23% in 2007 to 8% in 2017. Bhutan is also the world's only carbon negative country, with ~71% of the total land area under forest cover, leading to sequestration of nearly three times as much carbon dioxide as it produces. Despite its focus on improving the social safety nets of its people and green development, challenges persist. Income inequality and poverty, especially in rural areas, continue to be the country's major issues.

Bhutan earns most of its revenue from tourism. Overreliance on tourism can have long-term environmental impact. But, lack of round-the-clock power supply across all seasons impacts industrial growth. Hence, the backbone for improving the economy is reliable power supply.

The country meets majority of its power obligations through hydro capacities (~99% share), all of which are run-of-the-river. The availability of water in the river is high during the summer months and low during the winter months. Hence, the power generated fluctuates according to season - power generation is typically high during June to October because of the snow-melting and ensuing monsoon season, whereas November to April is the lean season.

Also, although energy demand throughout the day is similar in winter and summer, peak demand is significantly higher during winters at all hours. This situation poses challenges, as generation from hydro power plants is low in the winter. Furthermore, going forward, climate change can have negative impact on river flows, including seasonal reduction in flow and overall increased erratic flow patterns, thereby posing an energy security risk. While the river flow may decrease as the glaciers recede, increased monsoon rains may result in increased inflows, both of which are detrimental to hydro power production.

Power security can be improved by developing solar and wind plants in the country. Although large-scale RE development will remain restricted because of limited usable land and challenging terrain, small solar and wind solar plants (<10 MW capacity) can be developed in areas around urban centres. Community or node-based RE generation can also be expedited to improve the power supply position of villages/ areas falling under the node. This can improve cottage and small industries. Through rural entrepreneurship and skill development programmes, human capital can be improved. This can have a cascading impact on the overall wellbeing of the population.

Another area where the country can focus on is increasing the export of power to neighbouring countries, primarily India. Bhutan has already signed an agreement with India to supply surplus power from the 720 MW Mangdechhu hydroelectric project for 35 years. This can be further enhanced by adding solar and wind capacities. Rising power export will improve the foreign exchange position for the landlocked country, which can be funnelled by the government towards priority sector investments.

Improvement in transmission and distribution networks, along with solar and wind injection, can, therefore, have far-reaching impact on the overall economy of Bhutan. This, consequently, falls under the larger agenda of the government's Gross National Happiness of providing sustainable and equitable socio-economic development.

Although solar and wind forecasting measures are not part of the government's priority ambit at present, going forward, improvement of solar and wind generation in the country will allow the government to undertake measures for unbundling of the power systems.

India

India, where a major economic activity is through agriculture, the supply of power, especially to rural areas, is crucial for the accelerated development of the country. However, power supply fluctuates despite several rural electrification programmes undertaken by the Centre and states. Per capita power demand has remained low at ~1,148 kWh as on March 2020. Hence, despite the rapid growth in electrification rates, there is still large unserved demand for power in the country.

RE has the potential of improving energy security, while protecting the environment. It has several socio-economic advantages as well. With improvement of power access to the agricultural sector through the deployment of solar-powered pumps, irrigation and drinking water facilities can be significantly improved. This can improve the livelihoods of the rural populace in arid and semi-arid regions where, through proper irrigation, the land can be put to agricultural use.

In states such as Gujarat and Rajasthan, solar panels have been installed over canals to keep the water cool and prevent drying up of the water during the summer months. This water, in turn, is used for irrigation and drinking purposes for the neighbouring villages. Plans are also underway to set up floating solar plants on dam reservoirs to prevent water loss and improve hydro power throughput, especially during the lean winter season.

Renewables can be used for several other purposes as well, such as street lighting, train or metro stations, making buildings energy-efficient, and district cooling systems for ventilation. Some of these applications have already been deployed in the country, and can further be scaled up. This creates an ecosystem of clean energy generation and reduces dependence on conventional power. It can improve supply chains, leading to more OEMs, and increasing manufacturing of systems, and operation and maintenance services. The government has taken several measures for improving domestic manufacturing of RE parts in the country under the 'Make in India' initiative to increase job creation and enhance domestic capabilities.

Improving the power market and RE generation can increase foreign investment in the country. In fact, several global companies have set up wind and solar generating assets, while others, including private equity and multinational banks, have strategic investments in domestic companies with exposure to the RE sector. Going forward, foreign capital flows to the RE sector can improve the overall business ecosystem, spurring the setting up of more domestic companies and ancillary services. This can significantly improve employment opportunities in the segment.

As markets deepen and transactions on power exchanges increase, improved forecasting systems and supporting infrastructure can lead to further competition in the power sector, thereby attracting more capital.

With the rise in the power sector's contribution, as a percentage of GDP, the overall economy can be benefitted. This presents a strong opportunity to raising the standard of living of the population, through responsible and sustainable development. Improvement of average disposable income per household can also increase power intensity, and, consequently, social growth.

Maldives

The country is an archipelago of ~188 islands. The power sector is under-developed, with lack of generation capacities. All of the power generation capacity is hydrocarbon-based, with the fuel imported.

Because of the dispersed nature of the country, and challenges in interconnection among the islands, the government has adopted the policy of generating and distributing power primarily through islanding modes. Most of the islands have their own mini-grids with a diesel-based generation system.

Solar and wind based project implementation has been low owing to high installation costs and incidental challenges. Some solar-diesel hybrid systems have been installed in certain island nations to reduce dependence on conventional energy, and tide over unscheduled power outages. However, there is no large-scale RE generation. This provides an opportunity for Maldives.

Renewables can be looked at not only as a source of clean energy, but also as an important energy intervention to improve power access. The fisheries sector, which is one of the primary economic activities of the country, is an energy-intensive sector, which includes transportation as well as various manufacturing and industrial processes. However, energy access to the segment is not reliable. A strong power generation system, backed by solar and wind, can help improve its business potential and further develop potential niche markets.

The country's POISED programme is the first step in this direction, in which RE will be integrated into the power systems in 48 islands, through financing from multilateral organisations and donor agencies. This can be stepped up to build a largescale RE generation programme in several islands across the archipelago, lowering the requirement for conventional energy and improving decarbonisation of power.

As RE generation increases, forecasting of solar and wind is going to be key. Ground stations can be set up at strategic locations to capture real-time weather. A repository of past solar and wind generation data needs to be collected and maintained at the national level. Public utilities, STELCO and FENAKA, can be mandated to buy RE from generation plants to improve RE integration to the grid.

As solar and wind penetration rises, the country can significantly cut down on costly oil imports, which is susceptible to price and supply shocks. For an island nation, it will go a long way towards saving on fiscal spending while securing power supplies through clean sources. Investments in the sector can increase economic prosperity, leading to diversification and development of local industries. Regional inequalities and inequities can be resolved by improving access to opportunities, and providing social safety nets. A more equitable and inclusive growth can help the country position itself strongly as a tourist destination and attract tourists from developed countries. For the island nation, which is acutely impacted by climate change, it is crucial to adopt clean energy policies, also taking into consideration the socio-economic aspects.

Nepal

Nepal is a land-locked mountainous country, with plains covering the southern part, also referred to as Terai belt. This portion covers ~23% of the country's total area, and is the extension of the Ganges plain of India. The area is covered by tropical vegetation, and in some areas converted into agricultural land. This makes the region a conducive area for setting up solar and wind projects.

The country, due to its inclement weather and lack of access to basic facilities, has seen large scale migration from the upper hills to the Terai region and urban areas. This has strained power availability, which mostly relies on hydro-based capacities and imports from India.

Based on social parameters, per capita income is low, and a large section of the population is poor with limited access to social services. Furthermore, the country is prone to environmental degradation and natural calamities, such as landslides and earthquakes. Lack of a formal and an organised sector has led to a large section of the populace to take up unorganised labour. This has further increased social and income inequity.

Policy and government level intervention is required to improve the socio-economic condition of the country. Inclusive development can be fostered through the adoption of rural livelihood improvement measures. Small industries and community-based development can be undertaken in villages, where lack of formal education and jobs remain a barrier. This can improve rural employment and generate jobs. It can also undo the large-scale migration to cities, leading to equitable development across the country. However, rural development needs to be preceded by good rural infrastructure, with reliable power being the foremost. Renewables can help in achieving this, especially in areas located in the Terai belt, where elevation and steep landscape is not a challenge.

Grid security and grid access, though, needs to be improved to help in the uptake of utility-scale solar and wind plants. Furthermore, the Terai region, which is productive and cultivable, can make use of solar and wind generation for irrigation purposes, thereby improving land productivity and crop output.

But, hydro-based power generators in Nepal face seasonal impacts (especially in the winter months), hindering domestic power supply. Solar and wind-based power can address this by supplying reliable power in the winter months. With more than 70% of the population working in agriculture, this can create markets for high-potential agriculture value chains like tea and spices, significantly improving livelihoods. Large urban areas, with good power systems, can also look towards improving power supplies through solar and wind without compromising on grid security. The baseload hydro supplies can be complemented with solar and wind to provide reliable power supply throughout the year. This can help the country reduce its dependence on power imports while diversifying its power supply mix.

Therefore, RE-based power generation and grid access can have positive impact across communities and regions. While rural households can get access to reliable supplies and grid access to spur small industries and improve rural employment, urban areas can reduce dependence on imported power and unscheduled power outages through supply from domestic RE sources. Urban and semi-urban areas can improve land productivity by improving irrigation. This can lead to all-round socioeconomic development in the country.

However, large-scale RE deployment in the high mountainous areas make grid connections challenging and cost-prohibitive. These areas will continue to rely on distributed generation and patchy grid electricity, wherever possible.

Pakistan

Pakistan is a middle-income economy, with an estimated population of ~220 million, making it one of the most populous countries. Although the country's agriculture, industry, trade and services sectors have shown good growth over the years, the energy supply position has worsened, leading to a shortfall. Also, despite the country's abundant RE resources, generation capacity is primarily from crude oil and natural gas, which is imported. Increased use of furnace oil, contributed by IPPs, has increased the import bill and the current account deficit.

Lack of strong transmission infrastructure, over-reliance on expensive sources of power generation, and 'circular debt' issue of distribution utilities have increased the financial stress in the sector. Rising crude oil prices and depreciation of the Pakistani rupee have increased generation costs. On the other hand, government-controlled DISCOs, which purchase the power, delay their payments to generators owing to their weak financials and inability to pass on the rising cost of power generation to consumers, translating into a revenue-expenditure gap. These developments have had a significant impact on the overall economy.

The power crisis has caused losses to the industry, leading to business closures and job losses. The industrial sector has not been able to modernise, stalling product innovation and labour productivity. This has further eroded the value of exports, which already face competition from Bangladesh and China. Also, the country has not been able to expand its export portfolio beyond a few low value-added products, such as like textiles, carpets, leather items, and sports goods. This has stalled foreign exchange earnings, leading to a balance of payment deficit.

Power supply is a key determinant of a country's economic development and social prosperity, especially for a middle-income and developing nation like Pakistan. A large part of the rural population of Pakistan still does not have access to grid electricity. Domestic power generation can be increased by tapping the vast solar and wind resources available in the country. In RE-rich states of Baluchistan and Khyber-Pakhtunkhwa, solar and wind belts can be notified by the government, and IPPs can be entrusted in building generation plants. With availability of reliable power, node-based development can be kick-started, thereby attracting new investments towards industrial and commercial activity. With the influx of economic activity, more wind and solar plants can be put up. Subsequently, crude oil and natural gas plants can continue to cater to the baseload demand, while RE can help smoothen out overall RE power generation peaks and troughs. Such all-round development of the province, on the back of indigenous RE power generation, can lead to community development, upliftment of social needs of the area, as well as attracting foreign and domestic investments to set up industries. Employee opportunities for the people will increase, leading to improved job creation and social well-being.

Sri Lanka

The island nation has a large population (~65%) residing in rural areas and more than half of the workforce depends on agriculture. Other rural activity comprises fishing, livestock rearing, and forestry.

The economic policy of the country titled 'Vision 2025', chalks a path to prosperity, which includes social and economic development. Progress towards development of rural communities by building necessary infrastructure and encouraging people to set up small and medium enterprises has been envisaged.

Power security is an important tenet in achieving this economic prosperity. Although Sri Lanka has achieved 100% grid connectivity, power supply is an issue. Power generation is primarily provided by hydro plants (~33%), coal-fired (~33%), oil-fired (~30%), solar, wind, biomass (~3%), and gas (~1%). The country does not have exploitable coal and crude oil reserves, and all of the domestic requirements are imported. Also, dependence on hydro plants is subject to weather and season externalities. Recently, during a severe drought in the summer of 2019, the country was subjected to daily power outages of two hours to tide over the deficit, with rural areas experiencing more prolonged outages. With the rise in economic development, and expected surge in power demand, solar and wind resources can be used to meet peak load requirement, complemented by efficient demand-side measures.

Tapping of indigenous solar and wind resources can go a long way towards achieving power security in the country. Furthermore, development of solar and wind plants can open up the sector to international players. With the right technology and competitive tariffs, power costs can offset expensive imported crude oil-based power, and improve the country's balance of payment position. The government will have more available resources to invest in social upliftment, including poverty alleviation and social welfare programmes.

Also, for a small island nation like Sri Lanka, decarbonisation of power generation can have far-reaching environmental benefits, thereby reducing per capita carbon dioxide emissions.

4.3.4 Technical Knowledge

Afghanistan

Afghanistan has limited technical know-how for RE penetration, integration, forecasting and scheduling. International collaboration has also been limited owing to lack of focus of the government on renewables. However, this can be addressed by setting up unilateral/ bilateral agreements with global weather and RE forecasting agencies. Several agencies already capture relevant data (weather, solar irradiation, and wind speeds) at a global level, based on satellite imagery and certain on-the-ground estimations. Such systems can be of use in the initial phase, at a fee. But with the rise in RE generation, the country will need to invest in localised systems that can capture data with higher degree of certainty, and take remedial measures (in terms of dispatch) in case of weather and generation exigencies. Technical collaboration and knowledge transfer can be facilitated between the implementing bodies in the country (power regulator, power utilities, and individual power plant owners) and other developed countries, which have made large strides in the wind and solar forecasting area.

Bangladesh

The country does not have experience in setting up and operating wind and solar forecasting systems. This is because of the lack of RE penetration in the country and policy push to improve adoption. Large-scale, utility-scale solar and wind plants are low in number, and technical knowledge of domestic companies is limited. The public and private enterprises can collaborate and train local resources for system designing, installation and project management. Tie-ups with RE-mature countries such as India, or other developed markets, such as France, Germany, and the US can be considered. As the country improves RE adoption, complementary wind and solar forecasting measures can be developed. In the initial phase, collaboration with global systems can be worked out. As uptake rises, more sophisticated systems can be developed in the country. India, the country's neighbour, has made large strides in developing its RE market, and adopting wind and solar forecasting measures. Bangladesh can benefit from the technical expertise and knowledge of India. Public utilities, private entities, and government organisations of Bangladesh can tie-up with their India counterparts for further knowledge dissemination and training.

Bhutan

Successful adoption of RE and RE systems will require formulation and implementation of strategies for capacity-building. This will require enhancement of technical capacities and co-ordination in the country. Public sector institutions, government bodies, and private entities will be required to play a role in developing the requisite knowledge base. Capacity-building initiatives can be undertaken at all levels, including policymakers, government officials, private sector entities, as well as consumers. Government staff can receive on-the-job short duration training on specific subjects. A training requirement assessment metric can be devised at the federal level to assess knowledge gaps among stakeholders, and subsequently focus on knowledge transfer.

India

The country has the necessary technical knowledge to develop and scale up renewable power. Through collaborations and workshops with global entities, the public entities have stayed on the learning curve. Additionally, with international players in the RE generation as well as RE forecasting space entering the country, knowledge dissemination in the domestic market has been strong. Hence, India, on its part, can improve collaboration with the SAARC Member States to help them develop utility-scale wind and solar generation. The level of engagement can vary from organising workshops to assisting in the development of wind and solar plants in the countries through strategic investments by the public as well as the private sectors. Views on power market improvement strategies and policy development measures can be exchanged and discussed between India and the other SAARC Member States as well.

Maldives

Owing to a nascent market and lack of industry participants, technical knowledge in the RE space is low, and, consequently, solar and wind forecasting. As a long-term strategy, the uptake in renewables is inevitable. Hence, the country needs to prepare itself when it comes to RE deployment. Multilateral and donor agencies that Maldives works with can help in allocating resource for knowledge transfer in RE generation and forecasting. Staff and personnel can be seconded to developed nations to get a first-hand assessment of how RE power systems function. Also, technical and vocational education, and training programmes can be arranged through collaboration of domestic universities with globally-recognised ones.

Nepal

With very little experience in utility scale solar and wind plants, knowledge among domestic stakeholders is low. As a start, the relevant personnel and entities can be imparted training through collaboration with global technology partners. Universities and institutions in the country can develop courses and curricula on RE systems. Strengthening of existing units and development of new units (by recruiting rightly skilled people) can be made to enhance capacity-building. Key units can be carved out, focusing on planning, policy formulation, and research and development. Collaboration with relevant national and international institutions in the RE sector can also be expedited. The knowledge base of neighbouring countries in the SAARC region can be made to use - workshops and knowledge dissemination sessions can be conducted among the SAARC Member States, where each country can learn from the rest. By leveraging each SAARC Member States' strengths and experience, Nepal can improve upon its institutional capacities as well as technical capabilities.

Pakistan

In addition to policy and economic barriers, lack of technical knowledge is hindering the uptake of solar and wind generation, as well as development of the overall power sector. Despite the country adopting the first RE policy in 2006, uptake has been slow. Knowledge gap and technical expertise needs to be improved among policymakers and other stakeholders to develop a strong RE ecosystem. Lack of awareness regarding advantages of RE technologies, and high-risk perception of investment as well as uncertainty can be addressed. Understanding about relevant technical and cost considerations for setting up of RE plants can also be improved. Information and knowledge dissemination among stakeholders can be organised through implementing agencies, professional organisations, and subject experts. Going forward, experiential learnings will help narrow the knowledge gap.

Sri Lanka

The government-controlled CEB needs to source technical knowledge with respect to RE generation and RE forecasting, and improve the power market. A new vertical can be carved out, focusing on the overall development of RE generation and integration. While envisioning reforms, it is important to tap the experience and expertise of the domestic private sector. Workshops, both regional (among SAARC Member States) and global, can be conducted to improve technical knowhow of domestic players. Knowledge exchange programmes and seminars can be arranged with developed countries, having open and unbundled power markets. Collaboration with other advanced SAARC Member States such as India can be undertaken as well, through inter-government or among private entities of the two countries.

4.4 Role of Public and Private Sectors

The section discusses about the role that the public and private entities can play in adopting, developing and implementing strong wind and solar forecasting techniques in the country.

4.4.1 Public Sector

Afghanistan

Although the blueprint for RE development may look attractive, most models fail because of lack of policy support at the federal and state (or province) level. In the case of Afghanistan, the issue is far beyond policy level intervention, though. The stability of the government, sound business ecosystem, and long-term peace and integrity of the country are major risks.

Also, institutionalising public sector reforms is important. Furthermore, development of strong policies by reforming management systems and oversight is key to implementation. Support and coordination among government bodies will further help reduce bureaucratic delays. Public investments can also be improved towards generating rural livelihoods, agro-industries, backed by 24x7 power supply. With the rise in solar and wind generation, levelized costs will reduce in the country, helping renewables to become an enabler for the development of communities.

While the power markets continue to be weak, the same can be improved through reforms and interventions as the scalable cluster-based model takes shape. A strong supporting and enabling ecosystem will help stakeholders and potential investors to bring investments in the renewables space, along with forecasting systems.

Bangladesh

The country is already home to solar housing systems and off-grid solar PV. The government can augment grid supply and bring rural areas into its ambit. In order to encourage distributed generation, net metering regulations can be prepared. This will improve overall grid resiliency by moving from a centralised generation system to a decentralised one, without compromising on impact associated with RE integration.

BPDB and DESCO, which supplies power to urban areas of Chittagong, Comilla, Dhaka, Rangpur, Rajshahi, and Sylhet, can be mandated to source a certain portion of the RE power from solar and wind plants. Delivery points of urban areas can be selected, based on the strength of the transmission systems that can accommodate intermittency. For the other areas, transmission and distribution networks can be strengthened before injecting RE power. This can reduce overdependence on fossil fuels.

In the first phase, the power market can be developed at a regional level, and expanded thereafter. The existing electricity grid with India can be utilised by supplying power to the country, in cases of lower-than-anticipated peak demand and/ or intermittent rise in solar and wind generation. Regional and cross-border power regulations can be signed to make the grids resilient to transmit RE over extended distances. At the national level, firm policies can be set out to improve large-scale solar and wind penetration over the long run.

The government, though, is presently not focusing on renewables integration, and rather intends to set up additional coal- and gas-based power plants. However, the coal-based plants (Rampal and Matarbari plants) have run into severe protests from environmentalists, leading to inordinate delays in construction. The government is also constructing additional liquefied natural gas terminals to augment the depleting domestic gas supplies to power upcoming plants. This is counterproductive. The government, can, instead allocate resources towards developing a cleaner power generating station, powered by renewables.

Lack of policy and regulation in the RE space, though, remains a dampener. There is absence of tariff/ incentive to set up large solar or wind plants in the country. Wind and solar forecasting finds no mention in policy documents either. Strong guidelines from the government as well as an enabling framework for setting up of solar and wind plants will improve RE uptake. Improving the power sector and unbundling of the utilities can foster competition and improve efficiencies as well.

Bhutan

With Bhutan aiming to be a fast-developing economy, energy intensiveness is expected to grow. The government will need to set out strong policies to make available reliable and affordable energy. The country has still not developed a strong RE policy, highlighting targets and implementation plan. Firewood continues to be the main source of primary energy, owing to the lack of reliable power and energy sources. Based on a study carried out by the United Nations Environment Program (UNEP), solar and wind energy (both available in abundance) remain severely underdeveloped due to overdependence on hydro sources, high price of solar and wind components as well as lack of adequate financing. Cheap, readily-available hydroelectricity has diverted attention away from more sustainable energy sources. However, with improvements in technology and falling solar and wind tariffs, the government can put a renewed focus on their development.

Solar power is mainly used for rural electrification and home heating systems. The government can look at developing holistic frameworks to develop solar and wind plants in the country. At the initial phase, a few plants can be set up with the assistance of multilateral organisations. The BPC and Druk Green Power Corporation Ltd, the two public sector entities in the power space, can be stakeholders in the plants. Initial grants can be passed on by the MEA and DRE to reduce upfront costs and improve project bankability. Through the "must-run" status of the plants, power generated from the plants can be ensured to be injected into the national grid. Tariff subsidies can be provided for the initial years to improve uptake of solar and wind energy among DISCOs. At the national level, a Renewable Energy Development Fund (REDF) can be operationalised to focus on direct lending, grants and subsidies to solar and wind plants. This will help de-risk investments and mobilise private investors. By improving distribution systems, off-grid systems can be grid-connected, thereby allowing communities to have direct revenues based on tariffs, as determined.

India

The country is the most advanced amongst SAARC Member States in adoption of RE and power market development. However, more effective steps towards developing an efficient power market design can be developed. Long-term bilateral PPAs between DISCOs and generators dominate the majority of power procurement in the country, while the power exchanges make up less than 1% of transactions. This prevents efficient power price discovery in the market, leading to RE power curtailment and financially stressed assets.

The CERC has proposed the creation of a national market for purchase of power, where the entire quantum of power generated in the country will be pooled together and sold through a spot market. Participants can include all power generators, including those that have signed power supply pacts with DISCOs. The buyers and sellers will place their bids for required quantities and a settlement price will be discovered, as per the normal practice on power exchanges. With reduction in solar and wind tariffs vis-à-vis conventional sources, RE generators can sell a higher quantum on account of the market-based economic dispatch (MBED) principle. However, the policy is yet to be adopted.

While real time markets (RTMs) are expected to improve market liquidity for short-term power, allowing for more RE injections, the need for wind and solar forecasting will increase going forward. The CERC has also proposed a new competitive, market-based ancillary services design where RE resources can participate.

In order to accommodate RE in the real time and competitive markets, a more mature forecasting ecosystem will be necessitated. Additionally, policies can be improved to include the following: (a) Centralised (regional/ state) forecasting as against plant-level forecasting (b) Harmonising DSM regulations across states (c) Rationalisation of error bands for solar and wind forecasting, based on achievable weather forecast accuracy using NWP (d) Incentivising RE generators for supporting grid.

On the implementation side, forecasting is undertaken by private entities without much public sector participation.

Maldives

Owing to its small size and dispersion, policy-level interventions in the power sector have been disparate and non-cohesive. While areas like Greater Male' and Other Atolls have improved electricity consumption due to increased economic activity, other areas have fallen behind. Furthermore, the country is highly reliable on the tourism sector which is cyclical and cannot be forecasted. This dual vulnerability to economic and climactic shocks needs to be bridged by building macroeconomic resiliency. In the power sector, large amounts of foreign exchange (in the form of oil imports) can be reduced by scaling up domestic power generation through solar and wind.

However, public policies in solar and wind sectors in the country are weak. The government needs to participate in developing a clean power generation ecosystem in the country. The Ministry of Energy Authority (MEA) can come up with a guiding principle to enable remote monitoring and data collection from the wind and solar plants. Due to the large number of islands, a decentralised model may be used, the specifics of which can be notified by the ministry and other relevant bodies. Conformity with RE PPAs and RE scheduling needs to be institutionalised. A regulatory framework, approved by the MEA, needs to be worked out to develop regulation with respect to RE generation/ forecasting and to monitor compliance. On the generation side, utility investments in the RE space at the early market development stage can reduce the dependence on subsidies. With the scaling-up of investments and market traction, the government and government-controlled bodies can help create a strong and resilient ecosystem to attract private investments.

Nepal

The government has set out strong policies, offering subsidies to encourage solar PV penetration in rural areas with no access to electricity. Although the programme has proven effective in improving power access to rural households, the country needs to work on improving grid supply as well. Distributed solar/ wind based power is not reliable and is susceptible to frequent system crashes. This hinders holistic development of rural areas. The government needs to come up with strong RE policies, overshadowing the energy policy framework of the country. In the initial phase of solar and wind augmentation, the government can strengthen infrastructure and invest in generation plants through a public-private partnership (PPP). This will go a long way towards inducing further investments from the private sector. The country's Electricity Act can be amended to make solar and wind truly dispatchable while policy guidance can be provided for strong forecasting mechanisms going forward.

Allocation of land to solar and wind projects by ensuring an investor-friendly land acquisition policy can also help de-risk projects. As Nepal does not have vast tracts of open flatlands, certain solar and wind parks can be developed in suitable locations. Special incentives and tax breaks can help in co-location of plants of a specific technology (solar or wind), leading to better project management and land utilisation. However, large RE integration to one pooling station can lead to challenges in grid stability. Grid infrastructure can be augmented through public investments to accommodate infirmness by bundling with hydro-based power. Node-based development can be adopted by the public sector, either through total ownership mode or PPP mode to demonstrate the government's earnestness in the sector. This can be further scaled up or replicated in other nodes at a later stage.

Pakistan

The country has shortlisted a few priority areas in the country for wind and solar development. However, implementation is key. The government needs to come up with comprehensive solar and wind policies that can act as guiding principles for stakeholders. AEDB as well as the respective states can work in close cooperation to improve transparency. A provincial committee can be constituted with representation from federal power sector entities and the priority states to review and approve solar and wind project proposals and to act as a one-window facilitator for investors. In several cases, the conducive locations for setting up of solar and wind projects are far from the grid, leading to lack of investor interest. The RE resource load is not close to the traditional load centres. Evacuation of power from those regions would require grid enhancement and extension. NTDC can look at investing in strong transmission infrastructure to enable power evacuation from the plants and assuage investor concerns.

NEPRA has set out directives on competitive bidding for solar and wind energy in the latest draft RE policy of the country. Interest among private entities can be improved by providing financial and fiscal benefits. NEPRA has also amended the grid codes traditionally developed for thermal power projects to facilitate interconnection and power evacuation from wind, solar power plants.

With rise in uptake of solar and wind in the grid, it is very important for a country to invest in and set up strong RE forecasting systems. It is all the more critical for Pakistan where grid interconnection is weak. The country can devise a framework to design and develop wind and solar forecasting systems. Private RE IPPs can be mandated to capture generation forecasts and share the same with the power system operator, which can improve overall RE integration and grid resiliency. Deepening of power markets and unbundling of DISCOs can be looked at to improve competition, transparency, efficiency and power tariff reduction.

A power exchange can also be set up in the country to introduce trading and price discovery. Through day-ahead and term ahead markets, generators and sellers can make direct power transactions. The new Competitive Trading Bilateral Contract Model (CTBCM), an electricity governance regime, proposes to set up IPP-DISCO bilateral contracting. However, contracts without a spot market exchange can lead to a lack of price transparency and introduce counter-party risks.

Uptake in RE, coupled with strong wind and solar power forecasting, can introduce a short-term power market, attracting traders and consumers. This can improve the overall functioning of the power sector in the country.

Sri Lanka

Despite the country setting an ambitious target of generating 100% of its power requirement using renewable energy sources (including hydro), development of solar and wind plants has not been given much impetus in the short term. The LTGEP 2018-37 policy document, highlighting the outlook regarding share of coal and RE has been contested and debated amongst the government, CEB and PUCSL. The government can set up a high-powered nodal committee to assess, evaluate and project

RE targets for the country. The Electricity Act and the RE policies have set out Feed in Tariff (FiT) schemes to improve investor participation in the setting up of non-conventional renewable energy (NCRE) plants, including mini-hydro, solar, wind, biomass, tidal energy plants, etc. However, as per the Electricity Act, for NCRE projects with capacity greater than 25 MW, the government must hold at least 50% of shares or the number of shares determined by the secretary to the treasury and ministry. This can potentially restrict the development of utility-scale solar and wind projects in the country.

The country can develop strong and conducive policies for development of large-scale solar and wind plants. Presently, the country focuses majorly on developing small-scale solar PV plants with system size of ~1 MW through the 'Surya BalaSangramaya' program. The government can realign strategies to promote utility scale solar and wind projects as well.

The country's transmission and distribution segment would require significant investments. As per the country's submission, ~Sri Lankan Rupee (LKR) 279 billion ($ 1,811 million) will be required until 2027 to improve the country's transmission systems, most of which is expected to be financed by multilateral financing bodies. Large-scale solar and wind development will require additional grid strengthening and interconnections. The country's transmission segment, which is solely owned by the government-controlled CEB, can be opened up for private participation. This can bring in additional funds from private entities, easing federal pressure while strengthening the national grid using best-in-industry technology.

Cumulatively, a holistic ecosystem can be enabled by the government to attract investments in the solar and wind segments. CEB, the sole integrated utility across power generation, transmission and distribution, can be unbundled, leading to competition. Power markets can be deepened, by setting up a power exchange and enabling buying and selling of power through the spot and derivative markets. The participant pool of generators, including the solar and wind IPPs, can directly sell power to consumers at market-determined rates.

4.4.2 Private Sector

The forecasting (weather and RE) business is fast becoming a lucrative business for the private sector. The World Meteorological Organization concedes that breaking silos between public and private sectors is critical for countries to adapt to the challenges of rapid change in technology and the need for more and more accurate forecasting. While national meteorological agencies work on areas like data collection, analysis and provision, private sector's role is indispensable especially in the times of breakneck technological advances and public sector budget cuts. Strong public private engagement along with close ties with the academia will help in transfer of knowledge from labs and publications into the value chain. Globally, there have been several developments towards increased private participation in the space. In the US and Europe regions, private entities have been running their own weather models which can compete with NOAA's GFS or the European Model. Private sector has been playing the role of providing robust, reliable, cost-effective and complementary component. As an example, the National Centre for Atmosphere Research (NCAR) WRF model is a successful example of a community model with collaboration between public sector, private sector and the academia. Companies like Panasonic, The Weather Company (owned by IBM), AccuWeather Inc, BMT Argoss, Skymet Weather Services Pvt. Ltd are some of the prominent global weather forecasting companies from the private sector. In the SAARC region also, India has seen investments in the private forecasting space. Global companies like Climate-Connect and Statkraft have set up base in India and has been providing weather data to RE generation companies, while also providing end-to-end weather as well as RE forecasting services. India grown private entities like REConnect, Manikaran Analytics, Meteocontrol have been providing RE forecasting and scheduling services.

The country-wise prospects for private sector investments in the RE and weather forecasting are as given below:

Afghanistan

Private sector participation and investments have been limited in the power sector. Although there have been some foreign investments over the last five years in the RE generation space, these have mostly been in the form of pilot projects through donor financing. Scaling up of wind and solar will require large-scale domestic and international private participation. With the government already declaring power as one of the priority sectors, a resumption in private investment, backed by an enabling business environment, can kick-start growth in the war-torn country. However, private participation will require a strong business case and assured returns. While this may not be initially possible, funnelling of some donor funding into the RE space to re-invigorate the sector, as well as strong policy backing can boost investor confidence. The private sector development programme with investor-focused policies can reduce red tape and bureaucratic hurdles. The government needs to play a strong enabling role in the ecosystem development while allowing domestic private companies to thrive and flourish. Domestic companies in the RE generation space can use the opportunity to improve their technical prowess to set up solar and wind plants, using the latest technology. Going forward, with rise in RE penetration, the forecasting ecosystem will begin to develop. It is important that the government and federal bodies make use of the expertise of the private sector (both domestic and international) to set up strong policies for wind and solar forecasting. Forecasting reports may be sought by the power system operators from private players to assess model efficiencies and improve upon them going forward.

Bangladesh

Private investment in the RE generation segment has not been strong. The government had prepared a plan to generate ~3 GW of power from RE sources by 2021. As part of the initiative, unsolicited proposals from private investors to establish solar and wind projects were considered but the initiative has not been very successful. BPDB has issued LOIs to 18 companies, of which seven to eight companies have signed PPAs, but not a single big project has been implemented as yet. The government is identifying challenges and barriers in implementation and lack of interest among private investors. While the private sector’s lack of interest has stymied the fast-paced growth in solar and wind generation uptake, the country continues to lack the presence of forecasting techniques and strong power markets. The private sector can develop innovative and sustainable business models than can lower risks in the RE generation segment. Partnerships with national and international investors for capital needs can be looked into. It can also look at the potential for local manufacturing of key components like solar PV modules to cater to domestic and international markets.

Bhutan

The private sector needs to participate in the development of solar and wind ecosystem in the country. In the initial phase, wind and solar LCOEs are expected to be higher than hydro due to the lack of accessible locations and domestic market development. However, with more traction and a broader pool of project developers, access to finance will reduce, leading to a fall in cost of capital. Private entities can further avail benefits of scale and progress towards a more diverse and distributed technology mix. Going forward, with market maturity and increased solar and wind penetration, the private sector can also play a role in developing RE forecasting systems and adopting improved technologies. Furthermore, the private IPPs can deploy forecasting systems at the plant locations and share with generation updates and forecasts with power system operators. The government can, on its part, collate forecasting data in a repository and develop a holistic forecasting system across a wider geo-spatial area. Through collaboration between the data providers (private or government solar and wind IPPs) and the federal bodies at the central level, a country-wise forecasting system can be put in place. Through continuous feedback and improvement, the country will be able to adopt sophisticated wind and solar forecasting systems.

India

The RE sector has seen rising private sector investments and the trend is expected to rise going forward with more global players entering the market and tariffs falling to historic lows. In the wind and solar forecasting space also, several national and international entities have been operating in the country. With the introduction of RTM markets, RE generators have an incentive to sell surplus or not requisitioned power on the exchange. This can open up an opportunity among the generators to improve their forecasting systems, narrowing the forecasting window and improving estimates. As the buyers and sellers are provided with an opportunity to correct any mismatch of demand and supply “closer to delivery”, the importance of forecasting and scheduling is all the more important. Improved “learning” models using the best technology and data available can be implemented by the private sector forecasting entities. This will help power system schedulers and power off-takers gain more confidence in renewable generation.

Maldives

The government has made foreign investments in tourism easy and attractive by allowing 100% FDI and offering tax sops and incentives. However, power generation has not yet been opened up to the same extent. Development of utility-scale RE generation will require international investments due to the lack of domestic market readiness and technical knowledge. Local capacity for RE installation, operation and maintenance is essential for fast-tracked development. Local companies and educational institutes can come forward to develop the country’s RE-based power market. Private entities like buildings and hotels and resorts can also set up distributed generation, powered solar or wind. Potential investors can pool resources from multilateral organisations to deploy and develop RE generation till the time a strong local financing system is created. On the back of supporting policies, private sector investments can improve, led by a low-risk, level playing field.

Nepal

Unlocking private investments is key to the development of the RE ecosystem in a country. This fosters competition and reduces solar and wind tariffs owing to improved competition and scale benefits. Nepal has not seen any significant private investments in the RE sector due to tight regulatory control and a vertically integrated utility structure, thereby hindering competition. With solar and wind being a fledgling market, private participation has been miniscule. However, some private entities like Api Power Company Pvt Ltd and Risen Energy and Eco Power Development Company Pvt Ltd have lined up solar projects in the country, with many of them expected to be operational over the next 5 years.

Although a good start, more private entities may find interest in the sector going forward if business policies are accommodative.

FDI approvals can be streamlined and a sound domestic financing ecosystem developed to spur private entities' interest in the segment. Domestic firms can support the RE growth by bringing in innovative, tailor-made business cases to build up wind and solar portfolios. Through partnerships and MoUs with global entities, international best practices can be adopted. As solar and wind projects scale up, private entities can adopt best in class forecasting techniques to reliably assess wind and solar generation. This data can be shared with system operators who can dispatch power based on economic principles. Such a mechanism can help better prepare for uncertainties and plan for contingency reserves.

Pakistan

Pakistan had introduced a comprehensive renewable energy policy in 2006, making private investment in the sector commercially viable. The new draft renewable energy policy further intends to streamline private sector participation. Competitive procurement mechanisms, such as auctions, can significantly improve private investments in the solar and wind generation space. However, interest and attractiveness among investors will determine participation. The private sector can work closely with the government and federal bodies to develop investor-friendly policies. The PPP route can also be undertaken for development of utility-scale solar and wind plants to de-risk investments. Through funds mobilisation and improved competition, it will reduce the government's overdependence on public funds. Private sector can also work on rural electrification (policy-permitting) and develop mini/ micro grids with net metering arrangements. Pilot studies can be undertaken in RE-rich provinces and further scaled up. With the market maturing and the opening up of the power sector, private IPPs can sell power on the exchanges and to DISCOs through bilateral contracts. Wind and solar forecasting are an attractive investment space. Private entities can assist the government in setting out RE targets in each province, based on assessment of load flow patterns. Furthermore, with rise in RE injection, the private sector can play an integral role in modelling RE generation scenarios and ensuring the grid conditions lie under tolerable limits. A major prerequisite to enabling grid security is undertaking of wind and solar forecasting. The private entities can develop forecasting systems at the province level and enable optimum RE integration through collaboration and real-time data sharing.

Sri Lanka

The private sector participation in the segment can be manifold, from generation, transmission and distribution to setting up of RE forecasting services. However, accommodative policies will be key. The private sector can bring in new funds from the capital and debt markets and improve investments. The shortfall in mobilising funds by the government in the power sector is typically met by international investors. More private participation can stem the inflow of foreign capital and strengthen the domestic markets.

Additionally, private sector participation is limited only to the generation space in the solar and wind sector due to the lack of any enabling policy. LECO is the only corporate entity in the distribution space presently. A good ecosystem for solar and wind generation and further deepening of power market will require much more private participation. Both the public and private sector can work together to assess the impediments to implementation and iron out implementation strategies. PPP mode-based development can be taken up in the initial phase of solar and wind generation while RE forecasting services can be developed in collaboration with global entities.

4.5 Improved Forecasting and Power Exchange

Good forecasting measures by a nation can have measurable impact on the price discovery of power prices on exchanges. Over the past decade, with rise in intermittent RE across the globe, the electricity markets have deepened while wholesale electricity prices have fallen. As power generated from RE, especially wind is volatile and difficult to predict, the day ahead prices are prone to extreme behaviour, such as spikes or negative values. In countries like Germany, where RE is granted priority during dispatch and receives a feed-in tariff, such spikes in pricing is commonplace. The day-ahead prices, which in Europe are also called 'spot prices', are set around noon on the day preceding the delivery. In order to allow for unplanned events and changing weather conditions, day-ahead markets are complemented by intraday and balancing markets.

An RE generator, selling power through exchanges, has no pricing power and is a price taker. The generator needs to decide, in advance, how much electricity will be sold in the spot market. If it commits lesser quantity in comparison to actual generation, the excess generation needs to be traded in the intraday or balancing market. On the other hand, if the offered quantity is higher than actual generation, the generator needs to purchase electricity to service the day ahead contracts. This optimal decision of the generator depends on strong forecasting capabilities as well as pricing spreads between the different power markets. Better the forecasting capabilities, more transparent will be the bid and ask prices on exchange. Uncertainty in forecasting capabilities will expose the RE generators to generation and price risks. Finally, over or under committing balancing markets owing to grid integration challenges of RE will have economic implications. As per European power market structure, the balancing cost depends on the imbalance settlement price and the size of the renewable energy producer's deviation from the production plan. The difference between the planned and the achieved output multiplied by the imbalance settlement price is the balancing cost, and that cost is then distributed among the balance responsible parties. Lower the imbalance settlement period, higher are the chances for balance responsible parties to rectify intermittencies through access to intraday markets on exchanges. The European Union has reduced the imbalance settlement period to 15 minutes which leads to smaller errors and improved chances of rectification. However, such imbalance markets have an associated cost of balancing which can be very high if RE injection is strong and forecasting systems are not robust.

In conclusion, it is imperative for nations to build strong power markets, with exchanges playing a pivotal role. RE intermittencies can be smoothened with an interconnected, regional grid wherein participants can bid and sell power and prices are determined through market forces. However, forecasting capabilities are important for market liquidity and transparent price discovery. The economic cost of not having forecasting -backed exchange traded power far exceeds the initial investments towards setting up forecasting systems.

5 IMPACT OF THE PROPOSED FORECASTING TECHNIQUES ON SAARC NATIONS

5.1 Impact of Proposed Forecasting Techniques on Stakeholders

The stakeholders are dependent on the accuracy of the forecast systems adopted and the ability to use the forecast information in the overall grid-management decision-making system. The wind and solar forecasting system's efficacy helps in reducing costs for variability management of power generation. There is enough incentive for stakeholders to obtain high-quality forecasts and effectively use the same as input for other processes or trading systems.

- RE generators: In countries like India, forecasting of energy generation falls on generators. As per regulations, imbalance charges, resulting from deviations in scheduled output beyond a tolerable range, are imposed on energy providers. This increases project operating costs. Therefore, RE generators have to forecast power output to avoid payment of charges. Also, before undertaking construction of plants at a particular site, RE generators can undertake long-term forecasts at the location to assess project viability and profitability.
- Ancillary service providers: The forecast data for wind and solar generation as well as the uncertainties regarding the forecasts are important to assess the requirement of "closer to real-time" ancillary services and in turn, to maintain the operational reliability of the power system. In principle, with rise in variability and uncertainty of power supply, requirements for ancillary services go up, leading to scheduling and pricing of the services. Although variability for solar and wind is an uncontrollable factor, uncertainty can be objectively forecasted. This will allow ancillary services to maintain necessary reserves for different services (like regulating reserve, contingency reserve, fast frequency response, voltage control, and black start).
- System operators: Strong forecasting systems help system operators evaluate the supply side of load balancing with respect to the source of energy, dispatchability and reserves assessment. The relative cost of producing electricity from the available pool of power generators (including conventional and non-conventional) can help in evaluating dispatch economics and optimum cost of power generation.
- Transmission and distribution companies: Lack of in-firm RE forecast data can lead to load imbalances in the event of under or over-injection in electricity, leading to grid instability. It also allows the T&D companies to undertake system planning and augment existing infrastructure to accommodate RE energy. This will lead to improved RE integration with the grid while reducing curtailments.
- Power market participants: In the competitive power market, market participants have the option of trading electricity through spot markets, forward markets or bilateral contracts. A prior knowledge of power market price fluctuations helps suppliers to set up rational offers in the short term as well as design bilateral contract pricing in the medium term. On the demand side, market price trends and fluctuations can help undertake hedging strategies against the risk of price volatility. Good forecast systems are important to evaluate RE generation and in turn, short-term power market prices. This will allow for improved price discovery and power market liquidity.
- Policy makers: Incremental RE injection and RE forecasting systems require accommodative policies. Although RE forecasting is necessary for all stakeholders, it cannot be looked at in isolation. Policy makers would be required to come up with regulations that improve the overall power markets, including fostering competition, development of power trading exchanges, transmission planning, ancillary services planning and increasing overall RE penetration.

Strengthening power markets and accommodating RE generation will automatically manifest strong wind and solar forecasting systems. The avoidance costs, in the presence of forecasting systems, is high for all stakeholders and therefore, acts as an incentive for adoption of the same.

5.2 Country Wise Impact

Table 33: Impact of Proposed Forecasting Techniques on Stakeholders in Afghanistan

Stakeholder	Impact
Power sector institutions	• Capacity development and concentration of regional forecasting expertise at Zonal Renewable Energy Centres if they are empowered with forecasting responsibilities. • Distribution of the responsibilities to different centres may create room for non-standardized approaches which must be managed by a central body.
Meteorological agency	• With greater interaction between the power agencies and the meteorological agencies, the sensitization of the meteorological agency to sector specific challenges will be accomplished. • Capacity development and scope expansion will follow if additional resources are deployed towards achieving higher engagement in the power and energy sector.
RE generator	• Greater interactions with grid operation bodies and ZRECs and operational involvement may be expected from RE generators.
Forecasting agencies	• Given the very nascent stage of development in the country, forecasting agencies are expected to play a minimal role in operational forecasting but may be engaged by institutional bodies for weather forecasting services and consulting.

Table 34: Impact of Proposed Forecasting Techniques on Stakeholders in Bangladesh

Stakeholder	Impact
Power sector institutions	• Additional responsibility of forecasting for all capacity by SREDA or PGCB which will require additional resource allocation. • Centralized forecasting will lead to better understanding by the utilities of the variability and scope for higher penetration of wind and solar in the grid which would lead to greater insights for future planning and readiness. • Immediate impacts are minimal as the current capacities of wind and solar generation are inconsequential for grid management.
Meteorological agency	• Additional focus on non-extreme weather applications of meteorology. This will require customization of existing services and additional resources towards creating formal collaborations with the power agencies.

Stakeholder	Impact
RE generator	• Higher engagement with SREDA on operational challenges and self-forecasting may be taken up by the RE generators to better manage daily grid integration
Forecasting agencies	• Multiple forecasting agencies may be contracted by SREDA or PCGB for consulting and regular forecasting services. This can open up a market for forecasting agencies, leading to more resource allocation and system improvements

Table 35: Impact of Proposed Forecasting Techniques on Stakeholders in Bhutan

Stakeholder	Impact
Power sector institutions	• Additional resource allocation by planning and operation institutions towards deep studies on scope for RE integration whilst using hydro as a dispatch able resource. • As grid connected wind and solar generation is limited in scope, the utilities may take up planning studies for off-grid solar and based on long-term forecasting assist the planning of grid development activities.
Meteorological agency	• Studies on country specific benchmarking for wind and solar forecasting specific weather parameters by the meteorological agency will require contracting of external agencies to build on the existing capabilities. Funds towards such activities may need to be mobilized from international or national bodies.
RE generator	• Greater collaborations with institutional bodies on planning activities and understanding scope for capacity expansion.
Forecasting agencies	• Forecasting agencies may be contracted for consulting assignments on planning and benchmarking.

Table 36: Impact of Proposed Forecasting Techniques on Stakeholders in India

Stakeholder	Impact
Power sector institutions	• Studies on country specific benchmarking for wind and solar forecasting specific weather parameters by the meteorological agency will require contracting of external agencies to build on the existing capabilities. Funds towards such activities may need to be mobilized from international or national bodies.
Meteorological agency	• Greater collaborations with institutional bodies on planning activities and understanding scope for capacity expansion.
RE generator	• Forecasting agencies may be contracted for consulting assignments on planning and benchmarking.

Stakeholder	Impact
Forecasting agencies	• Studies on country specific benchmarking for wind and solar forecasting specific weather parameters by the meteorological agency will require contracting of external agencies to build on the existing capabilities. Funds towards such activities may need to be mobilized from international or national bodies.

Table 37: Impact of Proposed Forecasting Techniques on Stakeholders in Maldives

Stakeholder	Impact
Power sector institutions	• Additional resource allocation and oversight towards capturing all information pertaining to rooftop solar installations in the country. • Better information gathering and monitoring of rooftop solar developments will lead to better planning of grid development and a higher understanding of the scope for distributed rooftop solar to compensate for high levels of reliance on imported diesel-based generation.
Meteorological agency	• Capacity development towards incorporating solar specific forecasting capabilities and data delivery mechanisms to share data with relevant bodies.
RE generator	• Minimal impact on RE generators beyond registering all relevant installation and operational information with STELCO.
Forecasting agencies	• Forecasting agencies may be engaged by STELCO on consulting basis to assess impact of higher penetrations of solar rooftop on grid stability.

Table 38: Impact of Proposed Forecasting Techniques on Stakeholders in Nepal

Stakeholder	Impact
Power sector institutions	• Higher involvement in gathering and maintaining master data on installations of RE generation plants. • Resource allocation towards developing a system for capturing such data and ensuring reporting of data by generators. • As grid connected wind and solar generation is limited in scope, the utilities may take up planning studies for off-grid solar and based on long-term forecasting assist the planning of grid development activities.
Meteorological agency	• Greater collaboration with NEA for meteorological data sharing and capacity development at NEA towards better utilization of meteorological data by the NEA.
RE generator	• Minimal impact on generators aside from reporting of installation data to NEA and timely updates of any capacity additions.

Stakeholder	Impact
Forecasting agencies	• Forecasting agencies may be engaged by the NEA to carry out benchmarking studies and provide basic services of aggregate forecasting for the entire nation inclusive of on-grid and off-grid resources.

Table 39: Impact of Proposed Forecasting Techniques on Stakeholders in Pakistan

Stakeholder	Impact
Power sector institutions	• Resource allocation and concentrated focus on planning for higher levels of RE generation through benchmarking studies on short-term forecasting accuracies. • Engagement of private agencies on consulting assignments to assess readiness of government agencies for a wide-ranging adoption of forecasting of wind and solar for grid operations. • Following the general recommendations, a systematic approach towards static and dynamic data collection covering country wide wind and solar deployments will be crucial in future readiness for increased capacities.
Meteorological agency	• Increased collaboration with the power agencies in planning for greater capacities of RE in the country. Self-assessment and benchmarking of the weather forecasting capabilities of the meteorological agency in meeting the needs of wind and solar forecasting for the country.
RE generator	• Increased interactions with the AEDB on self-forecasting capabilities. Potential for higher responsibility in forecasting of their generation on an operational basis with regular reporting to the system operator.
Forecasting agencies	• Forecasting agencies may be contracted by both RE generators and government agencies for providing services. Consulting assignment for benchmarking studies may also provide opportunities for forecasting agencies

Table 40: Impact of Proposed Forecasting Techniques on Stakeholders in Sri Lanka

Stakeholder	Impact
Power sector institutions	• Increased resource allocation within the CEB towards forecast based management of wind and solar power generation and injection into the grid. Resource allocation by SLSEA as well towards benchmarking and planning studies in order to establish the framework for all future expansion of RE capacity operationalization.

Stakeholder	Impact
	• Benchmarking studies may be carried out in order to assess reserve requirements and instability that may be introduced by the higher levels of wind and solar generation as per government mandates.
Meteorological agency	• Higher collaborations with CEB and SLSEA towards meeting the requirements of the power sector. • Additional resource allocation towards power sector specific weather forecasting and data dissemination capabilities. The meteorological agency will also face competition from private agencies involved in this sector but may benefit from increased revenues if commercial deployment of NWP is successfully achieved.
RE generator	• Increased resource allocation within the CEB towards forecast based management of wind and solar power generation and injection into the grid. • Resource allocation by SLSEA as well towards benchmarking and planning studies in order to establish the framework for all future expansion of RE capacity operationalization. • Benchmarking studies may be carried out in order to assess reserve requirements and instability that may be introduced by the higher levels of wind and solar generation as per government mandates.
Forecasting agencies	• Higher collaborations with CEB and SLSEA towards meeting the requirements of the power sector

5.3 Conclusion

While all SAARC Member States, apart from India, are at an initial market development stage in terms of RE adoption, there is scope for accelerated development going forward. Countries like Sri Lanka and Pakistan, along with India, have been betting big on renewables.

Despite strong headwinds in the wind and solar sectors globally, most of the SAARC Member States continue to remain underpenetrated in terms of actual installations. Strong policy planning, implementation frameworks and public and private partnerships can help foster growth of RE in the SAARC Member States. Policy-level pushes like making RE must-run will reduce curtailments, while planned network strengthening projects to improve RE integration can improve business sentiment in a nation. With rise in RE generation, countries will be required to set up strong forecasting systems. Day-ahead and intra-day wind and solar forecasts needs to be undertaken to assess prospective generation. This can lead to base-load power supply planning, overall power dispatch and overall power market improvement.

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7 ANNEXURE

Annexure 1: Solar heat maps

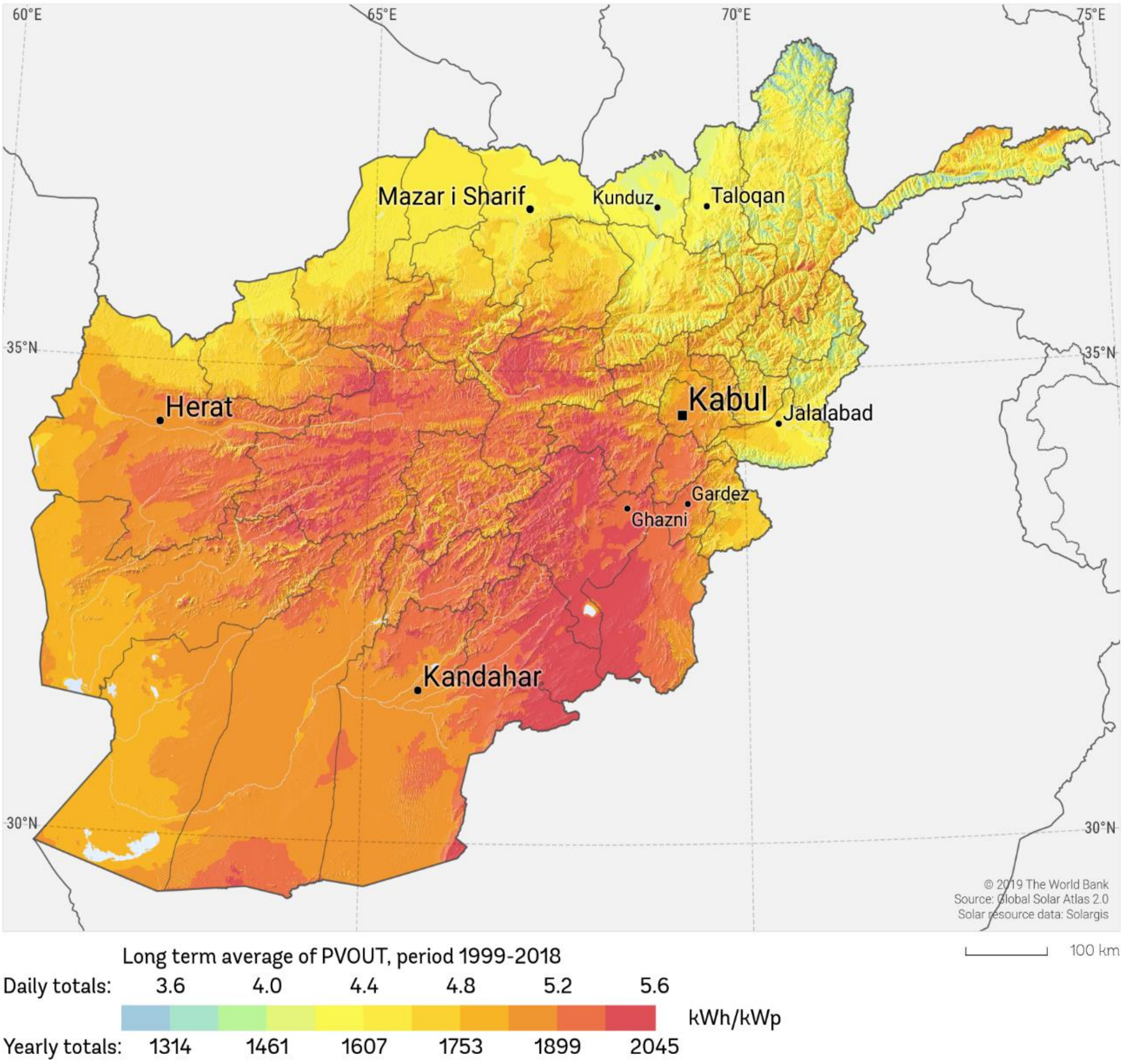


Figure 17: Solar Heat Map of Afghanistan (NREL)

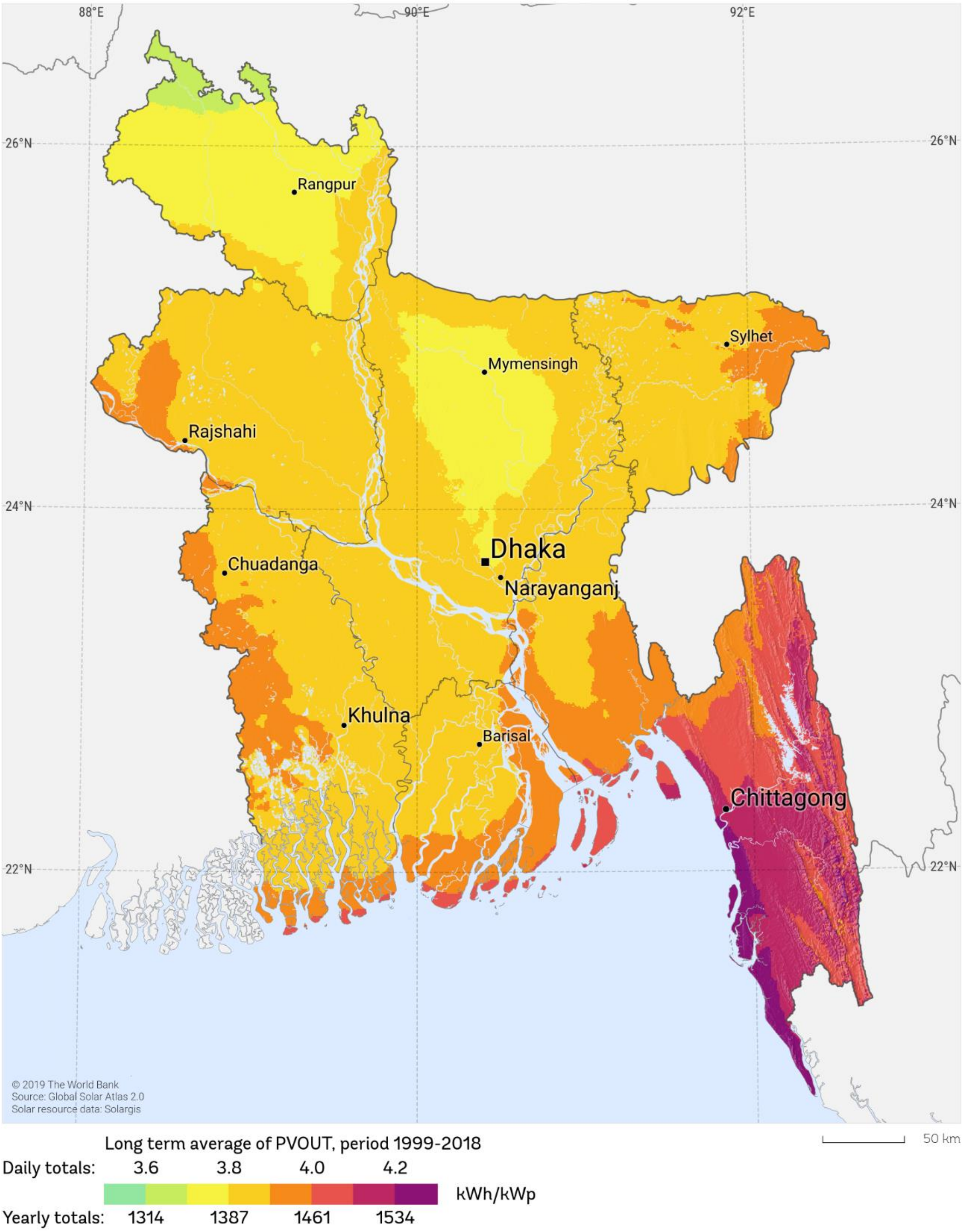


Figure 18: Solar Heat Map of Bangladesh (NREL)

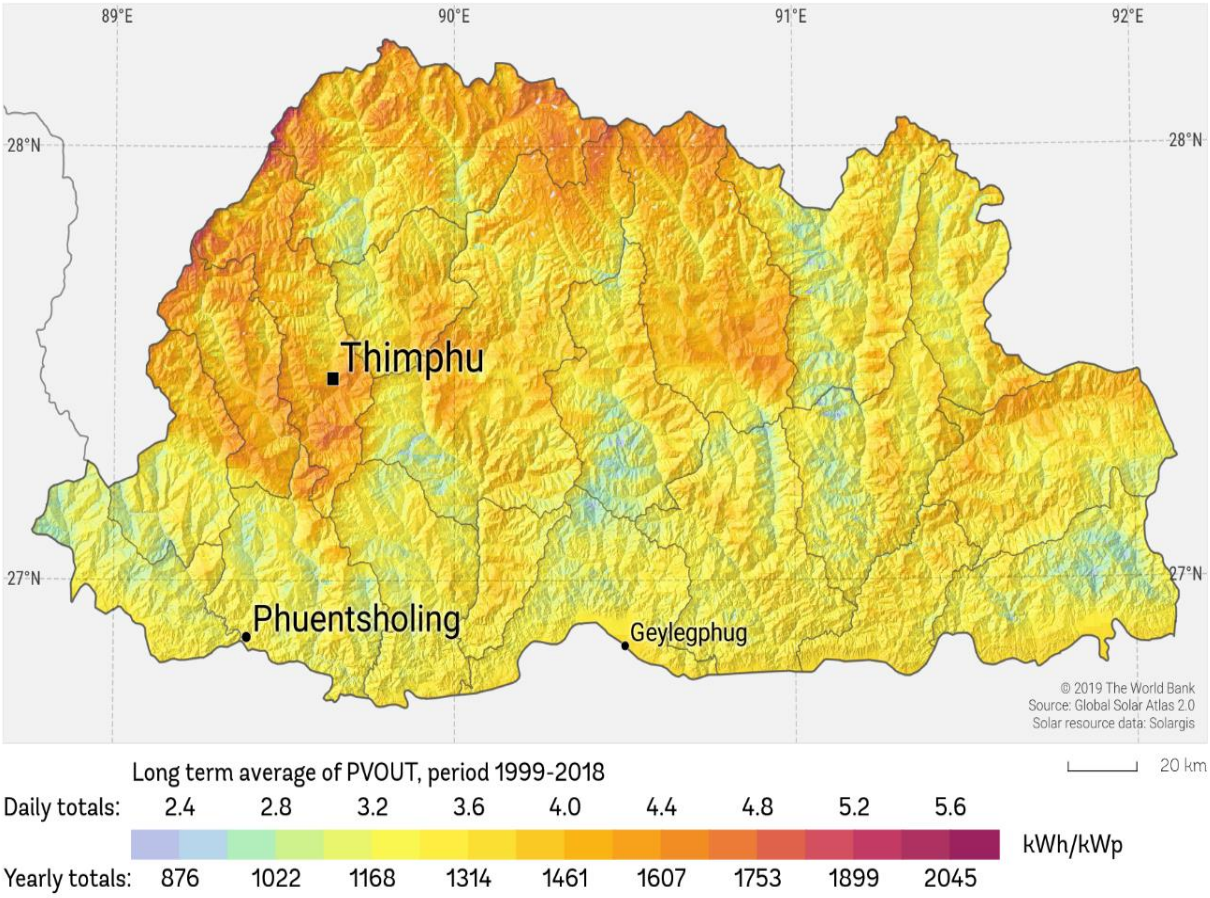


Figure 19: Solar Heat Map of Bhutan

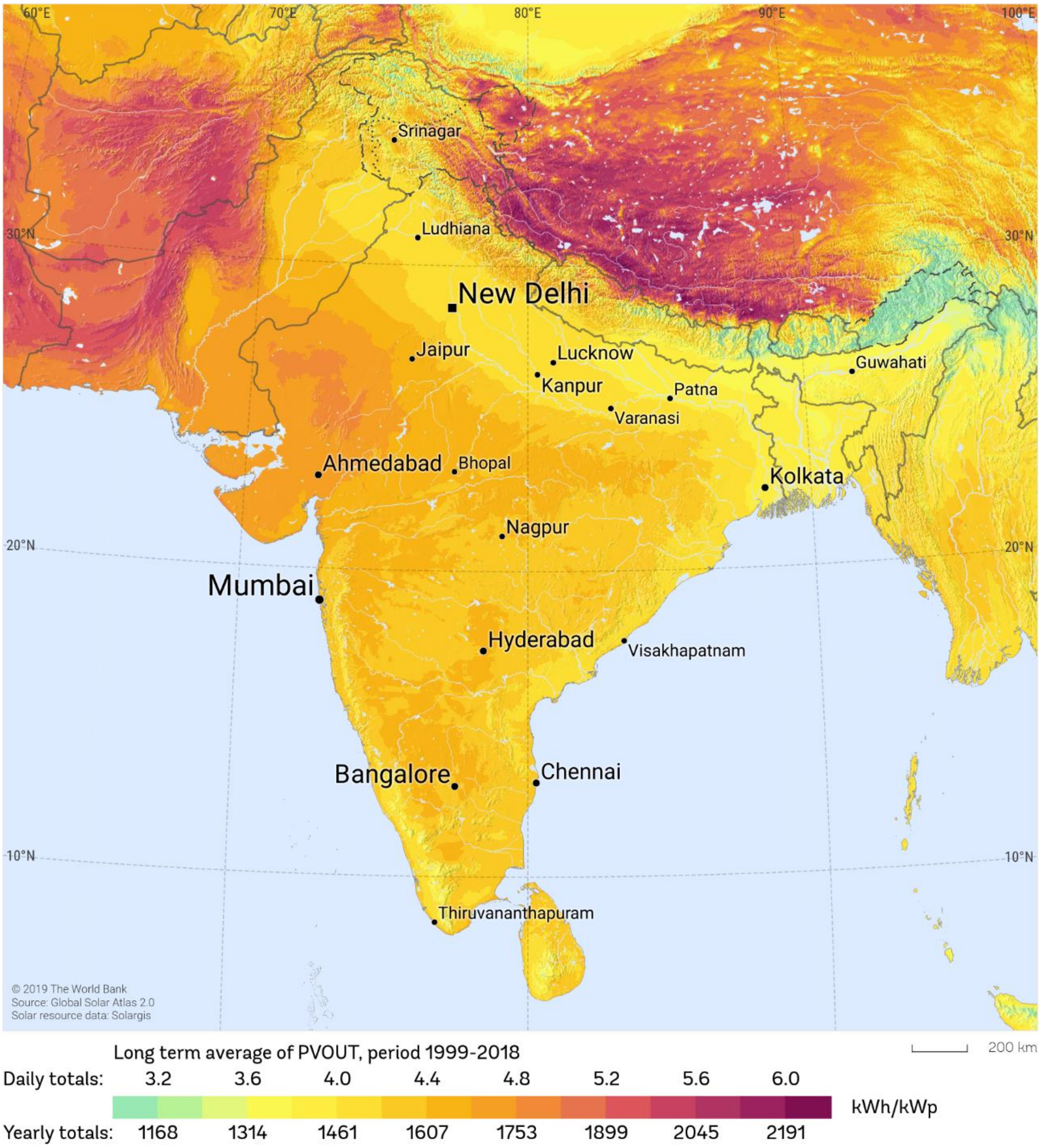


Figure 20: Solar Heat Map of India (NREL)

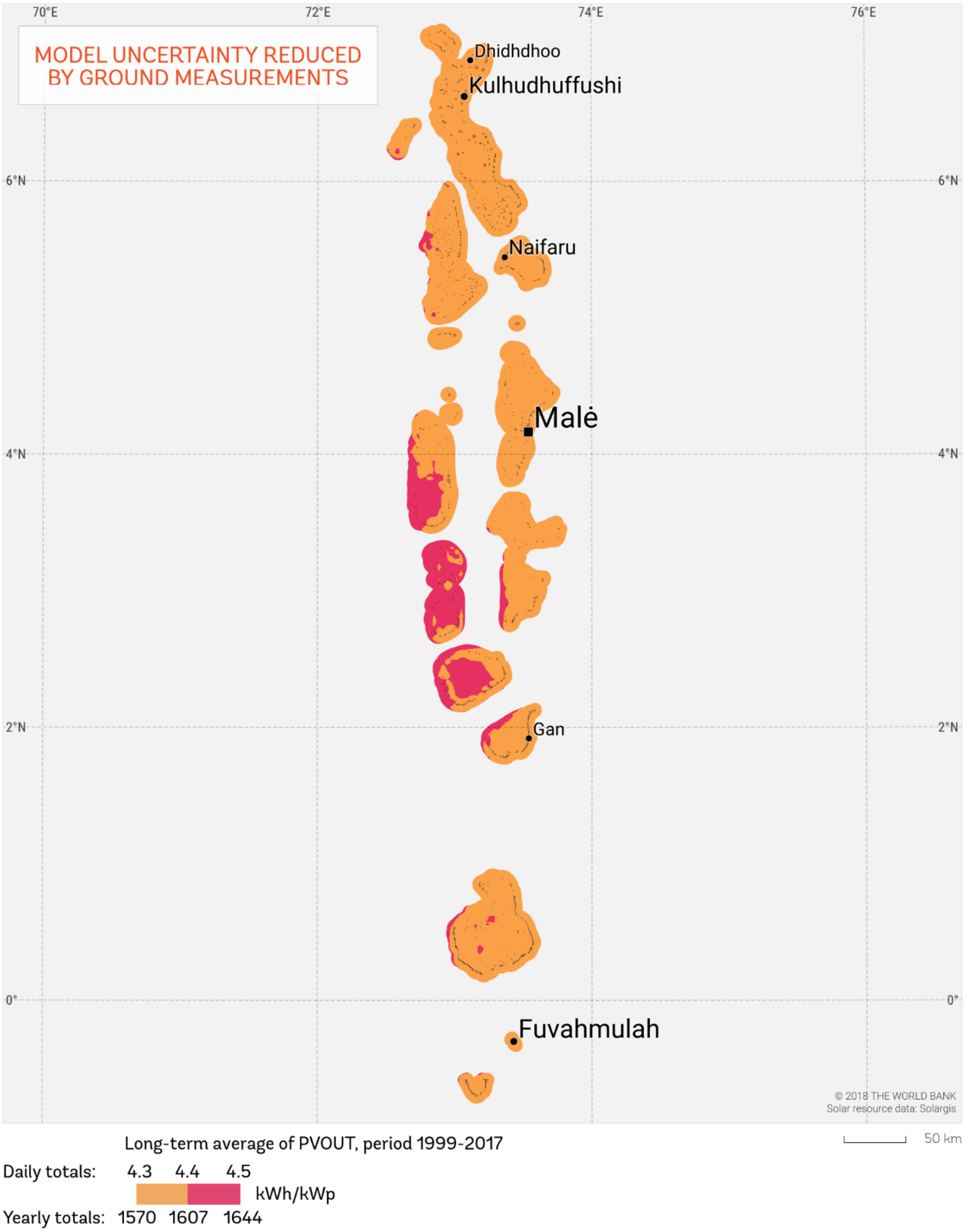


Figure 21: Solar Heat Map of Maldives (NREL)

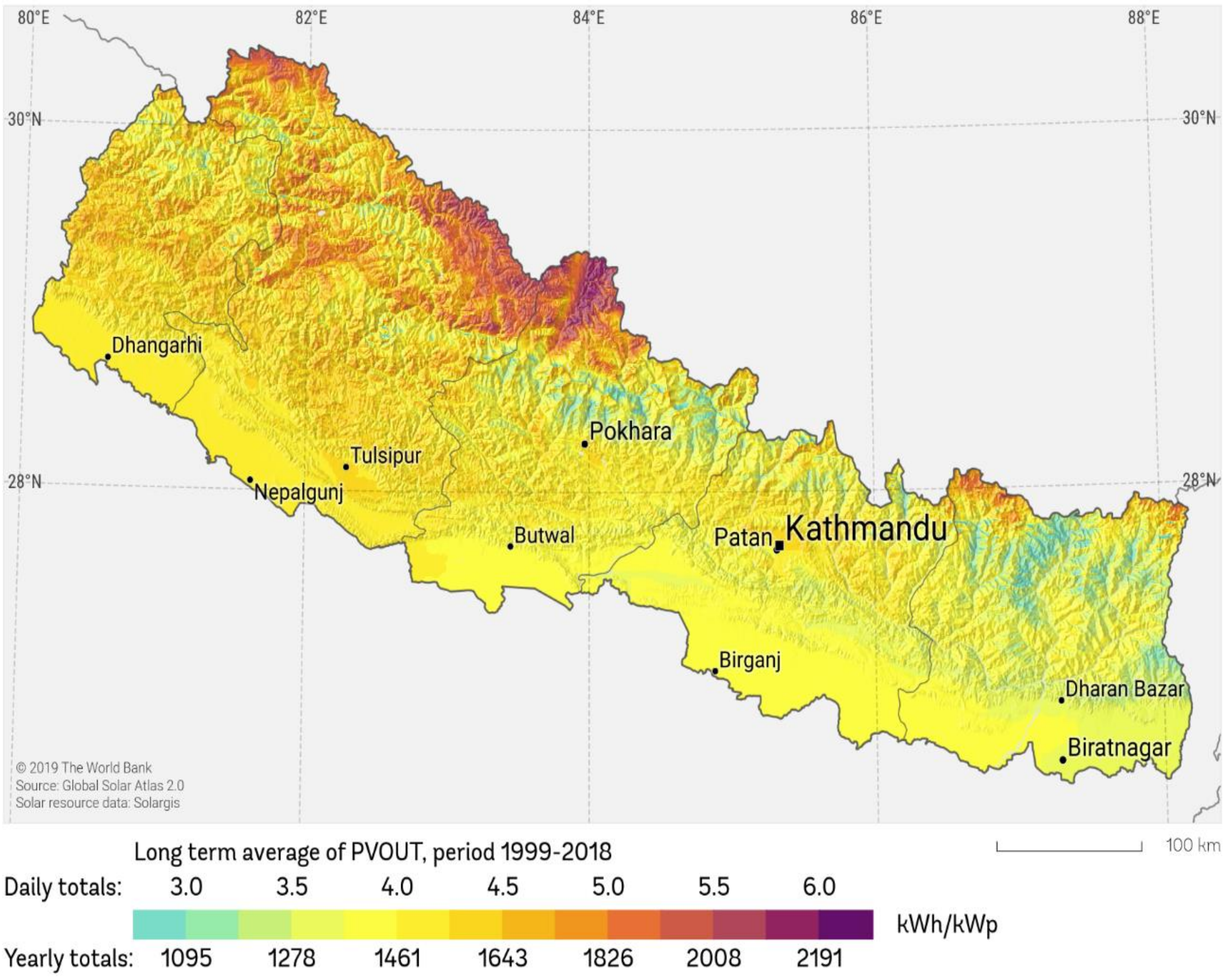


Figure 22: Solar Heat Map of Nepal (NREL)

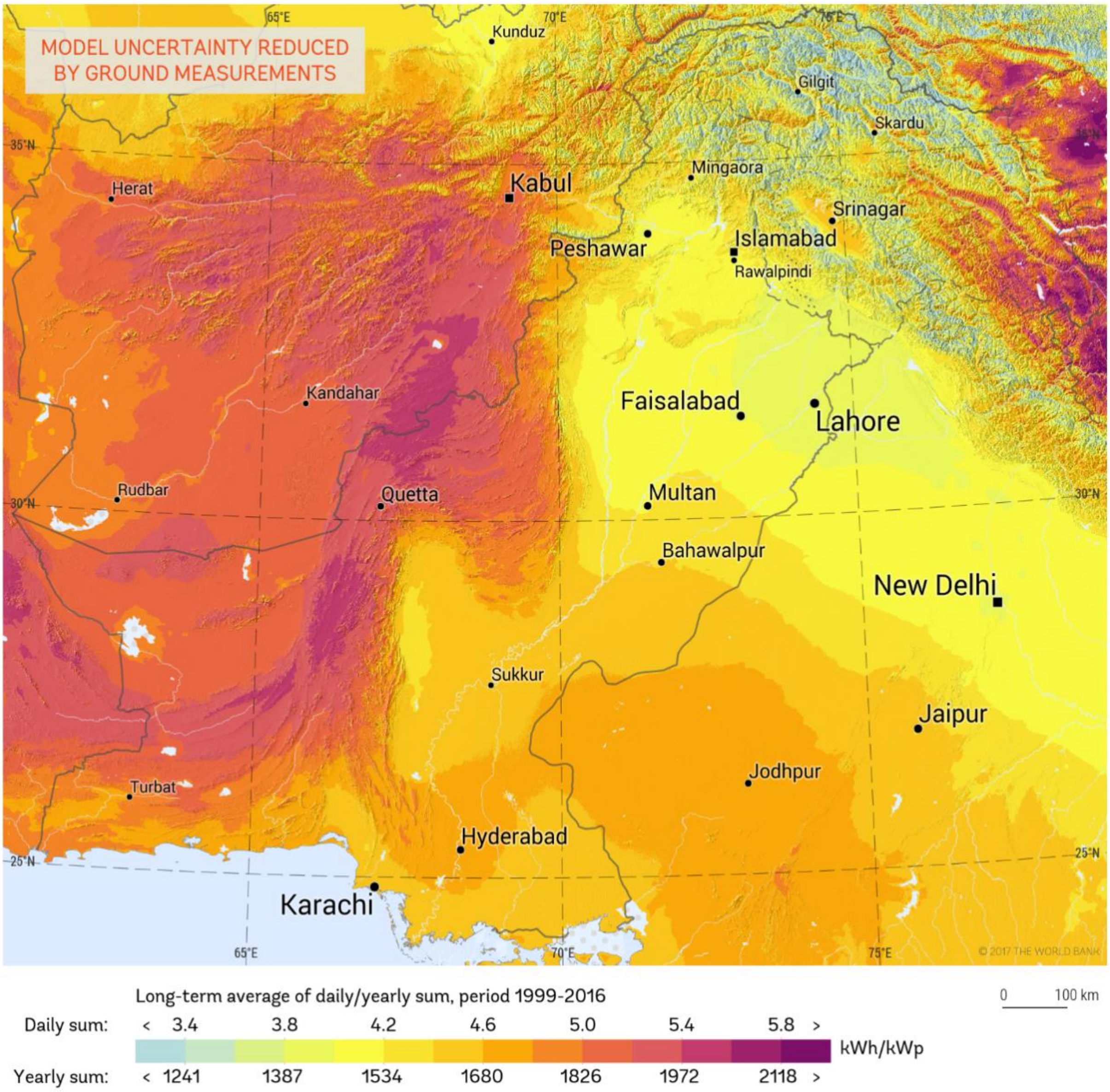


Figure 23: Solar Heat Map of Pakistan (NREL)

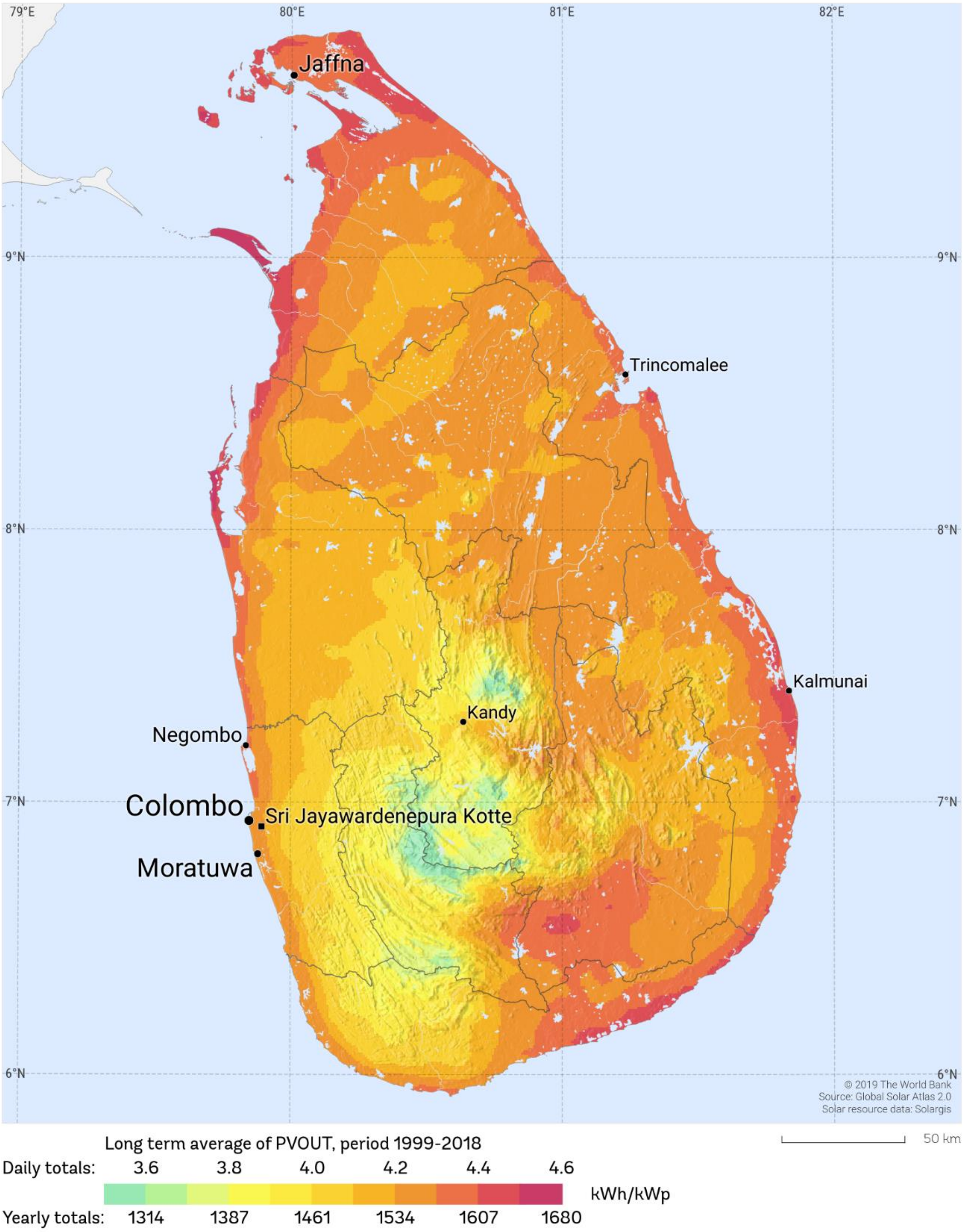


Figure 24: Solar Heat Map of Sri Lanka (NREL)

Annexure 2: Wind speed maps

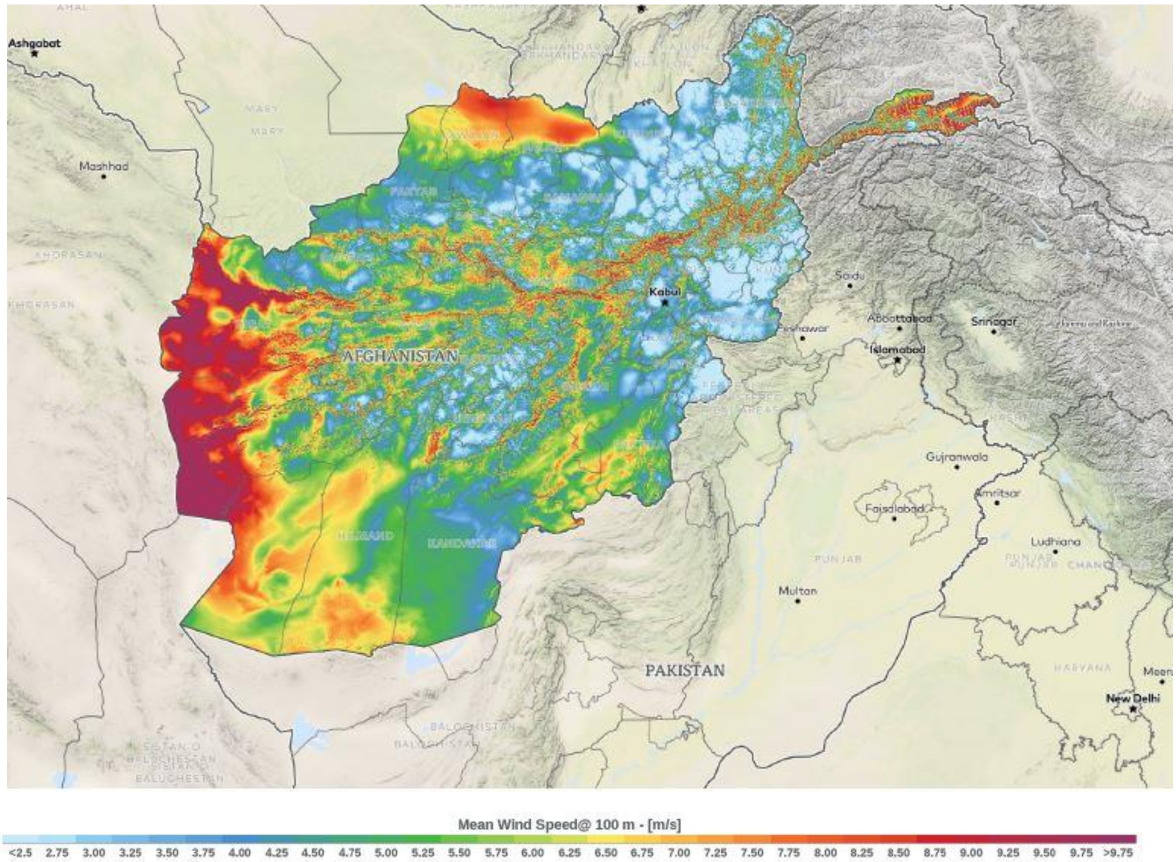


Figure 25: Wind Speed Map of Afghanistan

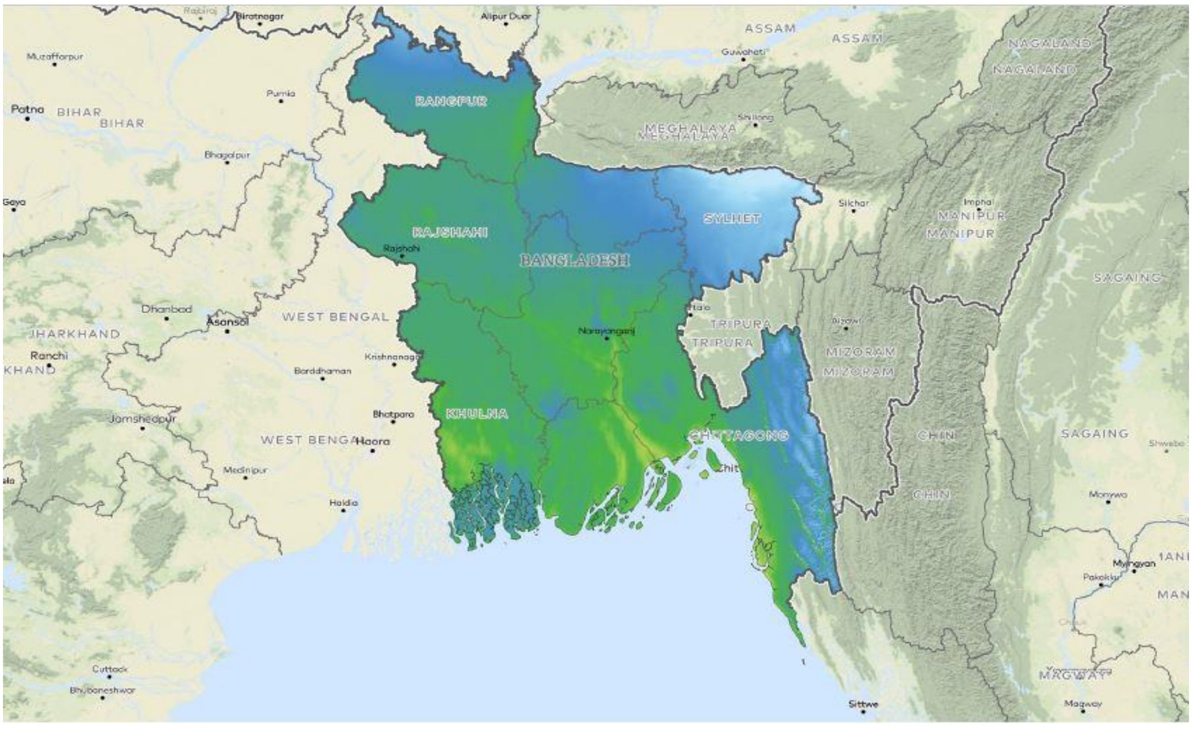


Figure 26: Wind Speed Map in Bangladesh

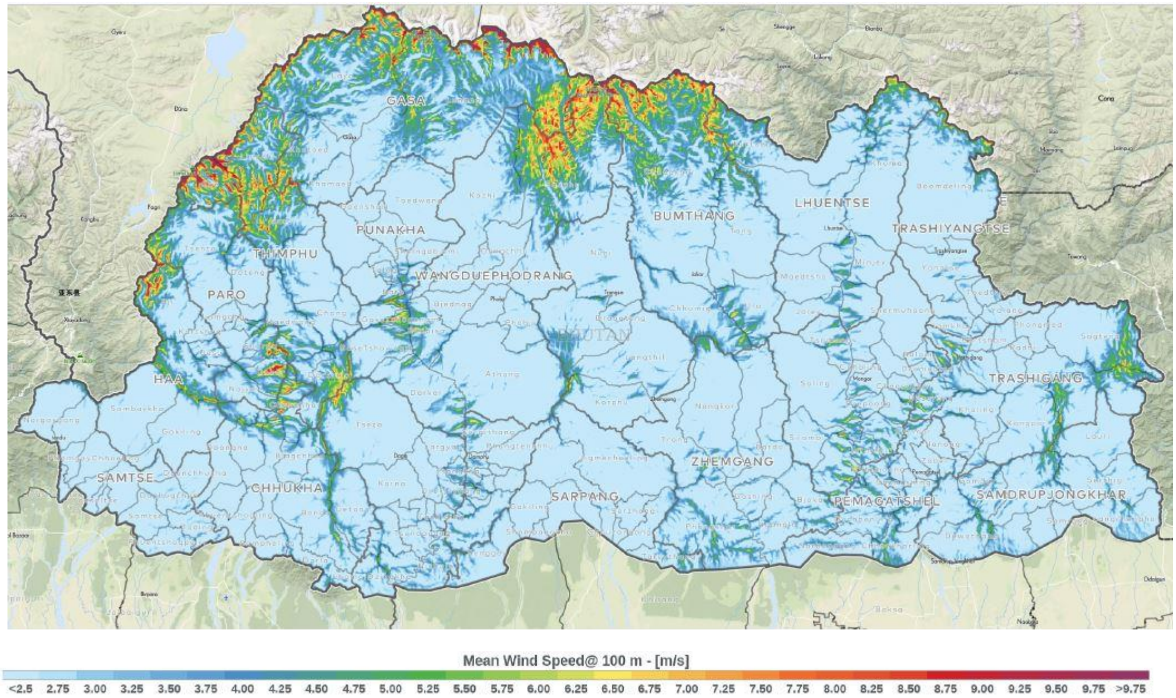


Figure 27: Wind Speed Map of Bhutan

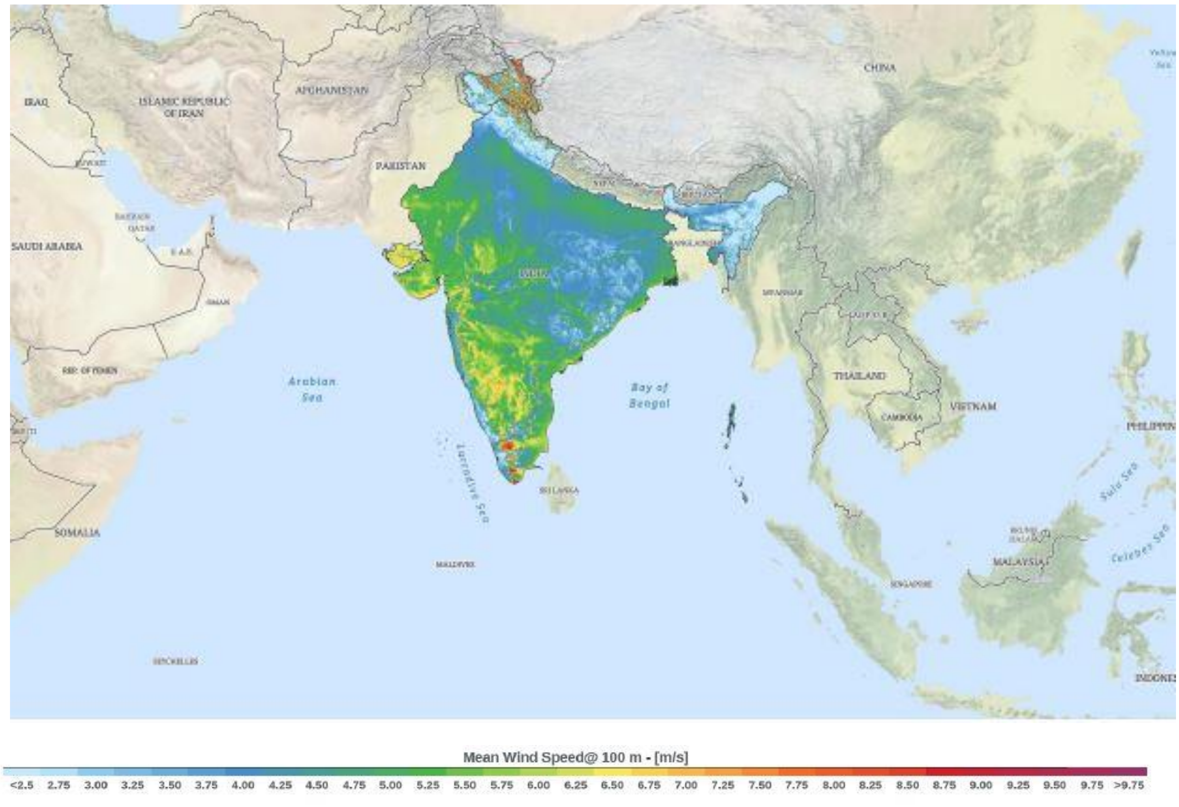


Figure 28: Wind Speed Map of India

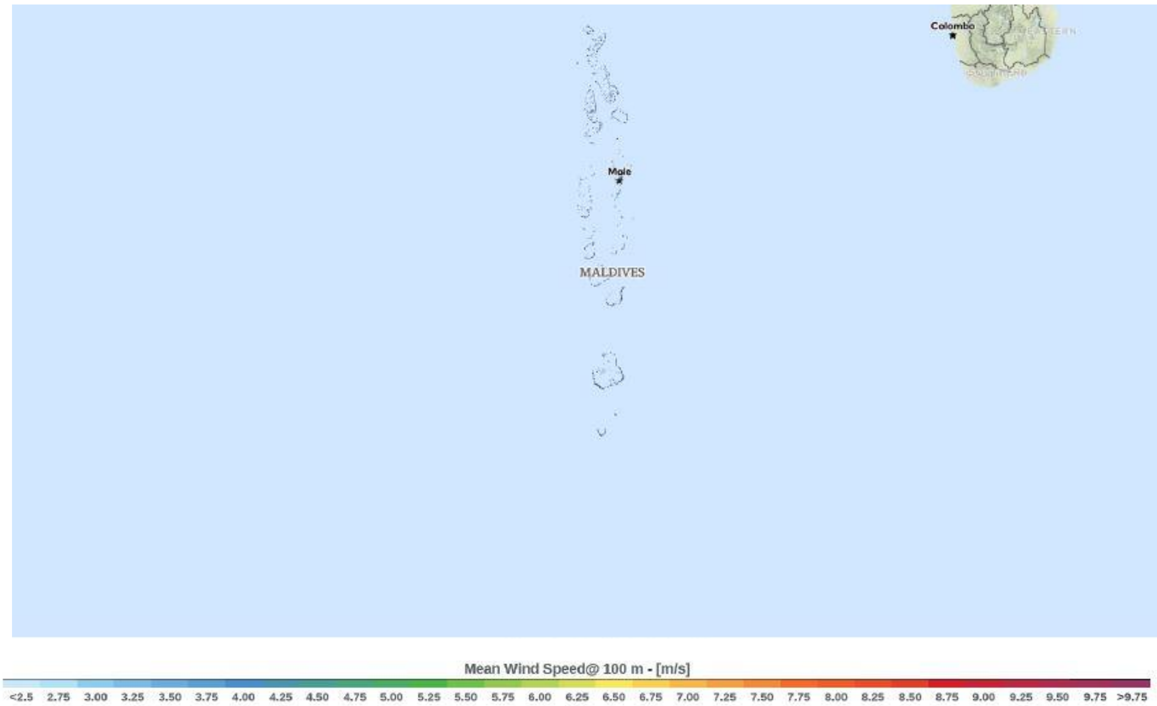


Figure 29: Wind Speed Map of Maldives

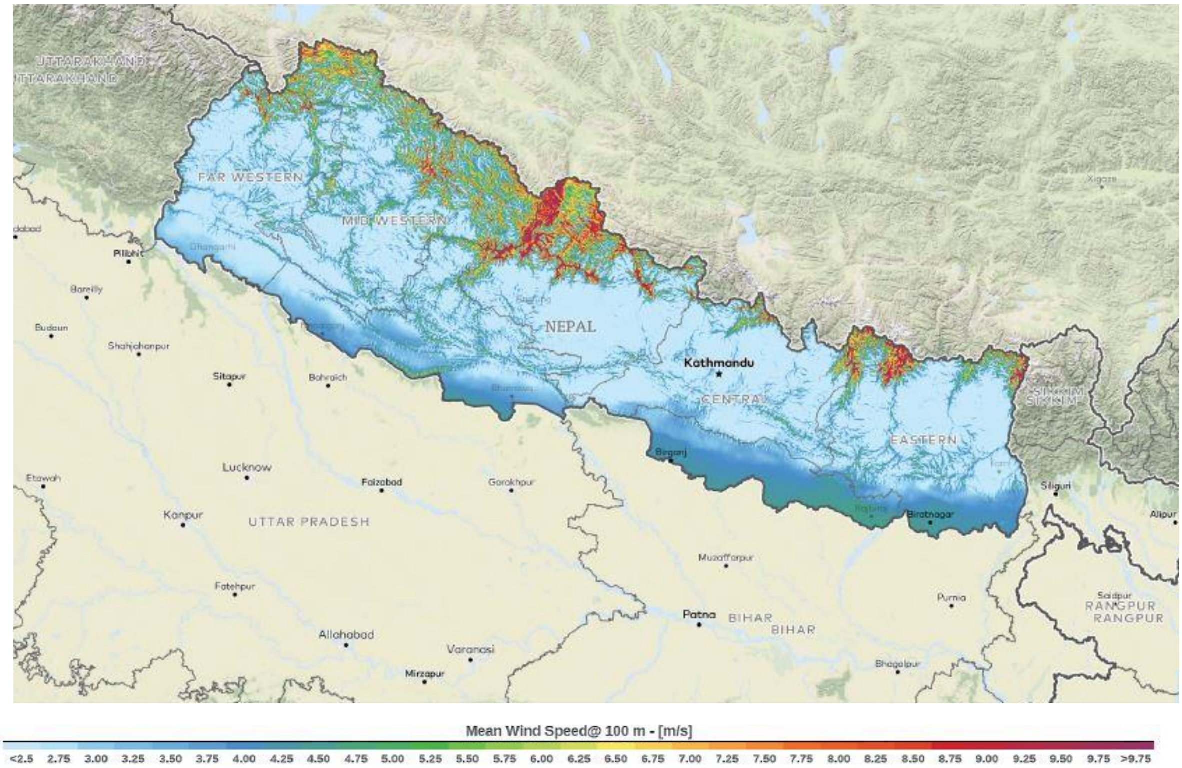


Figure 30: Wind Speed Map of Nepal

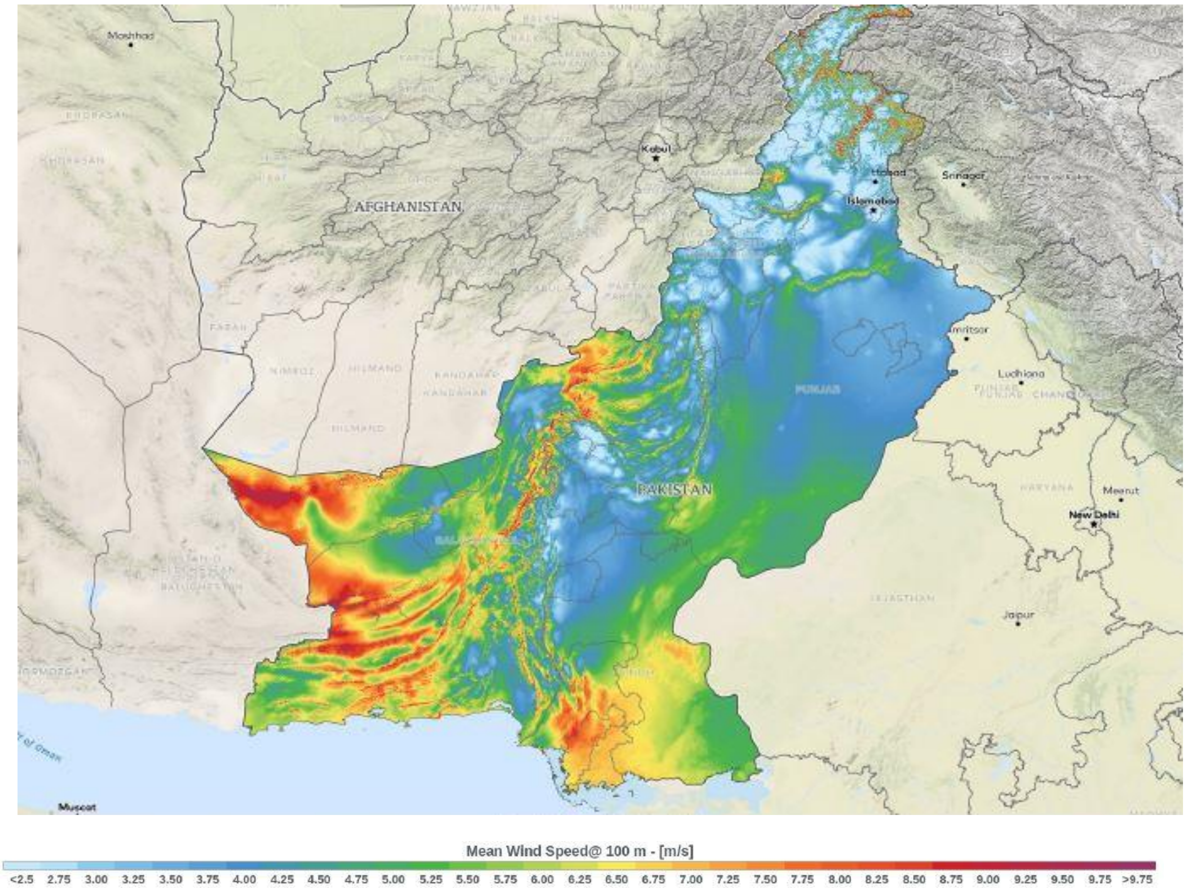
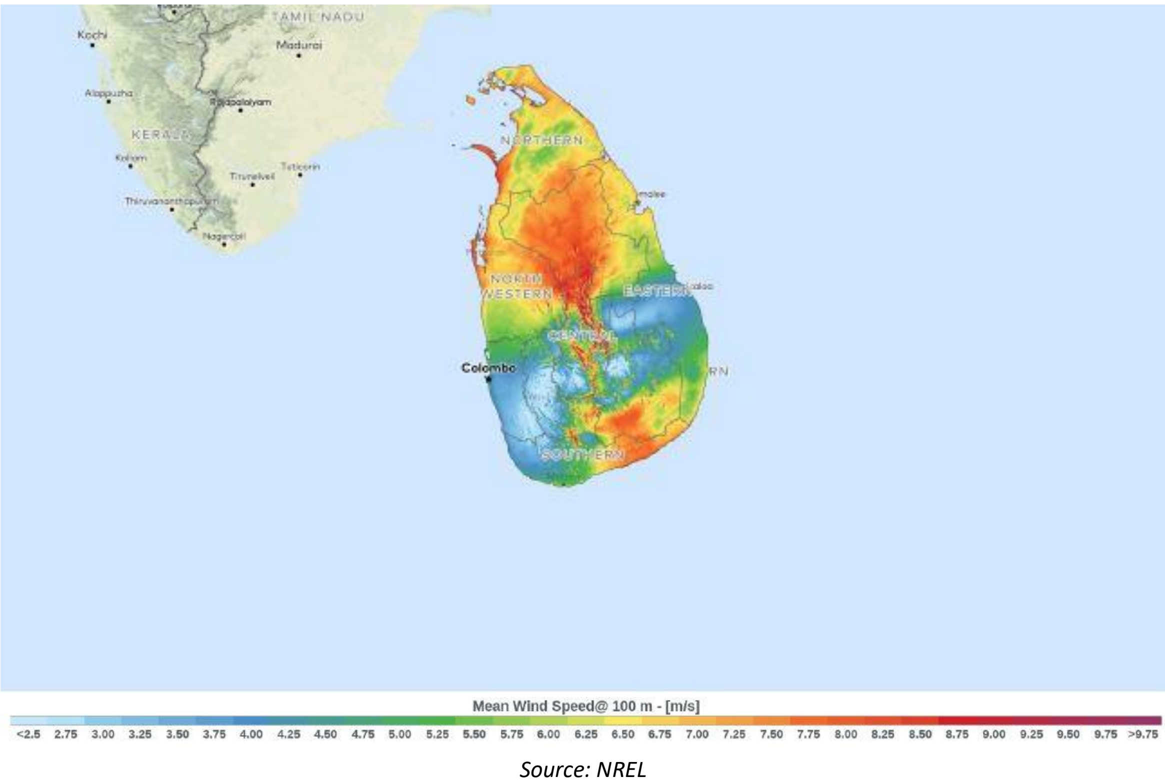


Figure 31: Wind Speed Map of Pakistan



Source: NREL

Figure 32: Wind Speed Map of Sri Lanka

Annexure 3: Survey Questionnaire

Table 41: Questionnaire for Meteorological Departments

Sr. No.	Questions
1	Does your organization/department generate proprietary global weather forecasts?
2	Does your organization/department generate proprietary regional weather forecasts?
3	Has the organization/department developed its own Numerical Weather Prediction (NWP) model
4	Is the organization/department actively working towards developing a proprietary NWP model?
5	Is the organization/department using forecast data generated by foreign meteorological departments?
6	Has the organization/department entered into MoUs/Support Agreements with any foreign nation's meteorological departments?
7	Please state the nation(s) with which there exist MoU/Support Agreements, if any:
8	Which of the following data sources are used by you/your organization?
9	Does the organization/department prepare a numerical weather forecast on a regular basis?
10	What is the forecast horizon (in days) for the numerical forecasts prepared by the organization/department?
11	What is the temporal resolution of the numerical weather forecast prepared by the organization/department?
12	What is the spatial resolution of the numerical weather forecast prepared by the organization/department?
13	Does the organization/department provide its numerical weather forecasts for use by external non-governmental organizations?
14	Is the organization/department currently providing its numerical weather forecasts to the power transmission, distribution and/or operations departments of the nation?
15	Has the organization/department deployed observational systems (AWS, Buoys, Weather Balloons, etc.) to monitor weather parameters?
16	How many observational systems have been deployed by the organization/department?
17	Does the organization/department share its observational data for use by external organizations/partners?
18	What is the temporal resolution of the observational data maintained by the department/organization?

Table 42: Questionnaire for Meteorological Departments

Sr. No.	Questions
1	How many numbers of wind power generation plants are installed in your control area?
2	What is the total capacity of wind generation currently commissioned and operational?
3	How many nos of solar power generation plants are installed in your control area?
4	What is the total capacity of solar generation currently commissioned and operational?
5	What capacity addition of solar has been planned until 2025?
6	What capacity addition of solar has been planned until 2030?
7	What capacity addition of wind has been planned until 2025?
8	What capacity addition of solar has been planned until 2030?
9	Is all information on installed capacity including the location coordinates of turbine/panel installations and the manufacturer/model available with the operators at the grid control center?
10	Is there a standard format for information collection from wind and solar generators at the time of registration/installation?
11	Have data communication links between the wind and solar power generation plants and the grid control center been established via SCADA systems?
12	If Partially (for 11), then what percentage of total wind and solar capacity is covered by data connectivity?
13	Is there an enforcement mechanism through which Grid Operators may ensure compliance of generators with operator advisories/requests?
14	Is there a planned system upgrade activity for SCADA systems in the next 5 years?
15	Are Solar or Wind power plants given priority status over other generation stations?
16	Is there an expectation from wind and solar generators to perform unit commitment activities in advance?
17	If Yes (for 16), how much in advance is the unit commitment expected? (select one or more options)
18	Is forecasting for wind and solar power generation carried out by the organization/department?
19	If yes (for 18), Is the forecasting done: (select one or more)