Renewable Energy 130 (2019) 536–546

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Renewable energy projections for climate change mitigation: An analysis of uncertainty and errors

Muhammad Indra al Irsyad [a, b, *], Anthony Halog [b], Rabindra Nepal [c, d]

[a] Research and Development Centre for Electricity, Renewables, and Energy Conservation Technologies, Ministry of Energy and Mineral Resources, Jakarta, Indonesia
[b] School of Earth and Environmental Sciences, University of Queensland, St Lucia, Queensland, Australia
[c] School of Economics and Finance, Massey University, Palmerston North, New Zealand
[d] CAMA, Australian National University, J.G. Crawford Building 132, Lennox Crossing, ANU, Canberra, ACT, 0200, Australia

ARTICLE INFO

Article history:
Received 13 October 2017
Received in revised form
30 May 2018
Accepted 20 June 2018
Available online 26 June 2018

Keywords:
Projection error
Commitment
Technical issues
Modelling
Policy

ABSTRACT

Failures of countries to set and achieve renewable energy targets are prevalent, producing uncertainty as to the possibility of renewable energy contributing to a reduction in global emissions. Lack of policy and incorrect modelling analyses are among the sources of these failures and understanding these two sources is crucial for improving confidence in renewables. We assess errors in projections pertaining to the capacity and production of renewable energy in the United States and those countries of the European Union that have strong commitments to green energy supply. Our results show that solar energy has the lowest level of uncertainty as it has the most achievable capacity projections. However, other renewables entail more attractive policies and further research is needed for the advancement of reliable technology and accurate weather predictions. Our findings also provide ranges for the projection uncertainties for six renewable energy technologies, drawing attentions to ways that the dominant errors in these renewable energy projections may be rectified.

1. Introduction

Increasing energy demand and the ongoing global push towards decarbonisation to mitigate the adverse effects of climate change have led to an intensification of renewable energy to stabilise emissions growth in the energy sector [1,2]. At least 133 countries have stated their renewable energy targets[1] [3]. Renewable energy has specific challenges such as higher investment costs, less reliable technology and intermittent supply issues. In light of these factors, political willingness profoundly influences the commitment to implement renewable energy targets by providing incentives, accepting higher electricity costs, settling contradicting policies and having weather-depended energy systems [4,5]. Nevertheless, government commitment does not necessarily guarantee the achievement of renewable energy targets. Intermittency and unreliable technology can cause overestimations as to the capacity factor of renewable energy. Such technical issues can become the main barriers to implementing proposals for 100% renewable energy supply [6–9]. For example, even China, the leader on renewable energy capacity, cannot maximise renewables-based electricity production as a consequence of grid connectivity problems and low-efficiency technologies [10,11].

One of the most common reasons for inaccuracies in energy projection is the using of incorrect assumptions [12,13]. O'Neill and Desai [13] and Winebrake and Sakva [14] suggest that incorrect macroeconomic assumptions are the sources of fossil energy projection errors, while Gilbert and Sovacool [15] view inappropriate policy analyses and wrong assumptions on capital costs and capacity factors as the sources of renewable energy projection errors. Policy—influenced by economic, environmental and political factors, which vary in each country—along with other institutional issues, determines the achievement of renewable capacity targets [16,17]. Conversely, technical issues (e.g., the reliability of technology, efficiency, the intermittency of resources and capacity factors) affect the achievement of electricity production targets.

* Corresponding author. Research and Development Centre for Electricity, Renewables, and Energy Conservation Technologies, Ministry of Energy and Mineral Resources, Jakarta, Indonesia.
E-mail addresses: muhammad.alirsyad@uq.net.au (M.I. al Irsyad), a.halog@uq.edu.au (A. Halog), R.N.Nepal@massey.ac.nz (R. Nepal).

[1] The setting of renewable energy targets is usually based on renewable energy projections; thus, we use the terms *target* and *projection* interchangeably in this article.

https://doi.org/10.1016/j.renene.2018.06.082

Several studies have already analysed the accuracy of renewable energy projections, but the scope of their analyses is relatively limited for drawing broad conclusions. Gilbert and Sovacool [15] focused on projections in the United States (US) Annual Energy Outlook (AEO) and thus their results could not capture global trends. In contrast, Metayer et al. [18] analysed global-level projections in the World Energy Outlook (WEO), but ignored the effectual nullification caused by an equality of failures and successes in projection implementation across each country. We extend the scope of our analysis to the US and to 27 European Union (EU) countries, each of which have strong motivations for green electricity supply. The US is the second largest country in terms of renewables capacity, while the EU countries are leaders in non-hydro renewable capacity per capita [10]. In addition, we examine dominant error sources by comparing errors in projections of capacity and production of renewable energy.

Our research questions are as follows: What is the most achievable renewable energy target? What are the projection error ranges for different types of renewables? Which error is dominant? Our analysis uses three indicators: *mean percentage error* (MPE), *mean absolute percentage error* (MAPE) and the *mean of the difference between absolute percentage error of capacity and absolute percentage error of production* (MDAPE). These terms are defined in Section 3.2 on methodology. The contribution of this study is threefold. First, our study guides policymakers to understand the uncertainties and errors in their renewable targets. Second, the results, by providing information about the most achievable renewable targets, may assist risk-averse countries to secure their energy supplies. Lastly, we identify issues that need more attention in renewable energy planning. The remainder of the paper is organised as follows: Section 2 discusses previous studies on energy projection accuracy, Section 3 describes the data and methodology and Section 4 presents the results of our analysis. Section 5 discusses the implications of the findings for renewable energy policy and Section 6 concludes the analysis.

2. Literature review

The use of energy models for making energy projections has been widely criticised on account of energy model limitations [19–21]. Energy models cannot correctly represent the complexity of future energy systems and commonly employ incorrect assumptions to address their unknown parameters [21–24]. The consequences of wrong assumptions and inappropriate policy modelling are not only limited to projection errors; they may also result in inefficient resource usage, excessive emissions and weaker energy security [14,18,25].

Therefore, analysing the accuracy of energy models is vital for deriving insights related to the uncertainty and inaccuracy of sources, which may then be used for adjusting the remaining projection data [13,14,26]. Metayer et al. [18] analysed the projections for various renewables in the WEO published by the International Energy Agency (IEA) between 1994 and 2014. They found that the IEA intentionally underestimated the renewables projections by continually using linear growth assumptions, whereas historical data showed exponential growth. The underestimated projections were for solar photovoltaic (PV) and wind energy, while other renewables had overestimated or relatively accurate projections. Gilbert and Sovacool [15], investigating the inaccuracy of six projections for renewables in the US AEO published by the US Energy Information Agency (EIA) from 2004 to 2014, found consistent underestimation of projections for wind and solar energies as a result of systemic errors in price assumptions as well as NEMS structure failures to capture policy effectiveness. Carley [27] and Shrimali et al. [28] supported their conclusions by empirically demonstrating the effectiveness of renewable energy policy in the US. Gilbert and Sovacool [15] recognised that the EIA initially overestimated capacity factors for solar and wind energies, but has ceased this practice in more recent projections. Nevertheless, both studies by Metayer et al. [18] and Gilbert and Sovacool [15] are not only limited in aggregate or confined to a single country, they cannot determine which projection (i.e., capacity or production) produces the greater error. Their analyses do not account for the influences of capacity projection errors in projection error analyses of renewable energy production.

3. Data and methodology

3.1. Data

The analysis of renewable energy projections in multiple and committed countries will have more robust results than an analysis in a single country. The size of renewable energy capacities reflects a country's commitment and the six countries with the leading renewables capacities in 2016 were China, the US, Germany, Japan, India and Italy [10]. However, China, Japan and India are excluded from this analysis because of the unavailability of projection data for renewables-based electricity production; ANRE [29]; METI [30]; MNRE [31,32] and Moch [33] only present the capacity projections for these countries. The EU countries have stated their targets for renewables capacities and production in the National Renewable Energy Action Plan (NREAP) [34] and actual data from 2010 to 2016 is available at EC [35]. The US EIA annually publishes various energy-related projections in the AEO, along with the actual data [36,37]. As does that of Gilbert and Sovacool [15]; our analysis uses the reference case scenarios from AEO 2005 to 2016. Data and the calculation results for all countries are available in the Supplementary Material.

Most capacity and production projections are available for all renewable energy types, except for solar thermal. Solar thermal production data for EU countries and solar thermal capacity data for the US are mixed with actual data for the photovoltaic. As a consequence, we merge solar thermal and PV in this analysis. Further, all countries do not treat hydropower data equally; for example, Swedish actual data covers conventional and pumped-storage hydropower, whereas only actual data for conventional hydropower is retained by the UK. Therefore, in the analysis results provided in Table 3, a country is given a note if the analysis includes pumped-storage hydropower. In summary, the total renewable energy capacity target[2] for the US and the EU in 2016 was 560.3 GW, consisting of hydropower (40.3%), wind energy (39.3%), solar energy (11.7%), geothermal energy (0.8%) and ocean energy (0.1%).

3.2. Methodology

We use the approach of Winebrake and Sakva [14] who use the MPE to show error patterns in the short and long term. MPE is defined as the average error between $\widehat{Y}$ projection data and Y actual data for n number of projections in τ year projection horizon and j energy type as in Equation (1):

$$MPE_{\tau,j} = \frac{\sum_t \frac{\left(\widehat{Y}_{t,\tau,j} - Y_{t,\tau,j}\right)}{Y_{t,\tau,j}}}{n_{\tau,j}} \quad (1)$$

Here, t is the projection publication year. MPE shows the error

[2] Based on AEO 2010 and NREAP.