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Looking the wrong way: Bias, renewable electricity, and energy modelling in the United States

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A B S T R A C T

The United States Energy Information Administration releases an AEO (Annual Energy Outlook) projecting future supply, demand, and resources for energy and electricity in the U.S. It is widely relied upon for policymaking. This study assesses twelve years of these projections of generation and capacity for six classes of renewable technologies. It finds consistent under projections for most renewable energy types in the mid- and long-term, due to inaccuracies, limitations, and inconsistencies in the underlying model. It identifies and evaluates five hypotheses that may explain such inaccuracy: inaccurate modelling of state renewable energy mandates, expiration of renewable tax credits, flaws in modelling structure, a biomass co-firing assumption, and capital cost projections. Unless AEO's projections of renewable energy are greatly improved, the reliability of its sector-wide electricity projections is inherently low. Key modifications suggested by this study include: fully valuing financial and non-financial benefits of renewables, improving cost innovation expectations for renewable energy, and, perhaps most importantly, properly modelling state renewable energy mandates.

1. Introduction

Historian Peter Novick once joked that the process of compiling data amounted to trying to "nail jelly to the wall." [1] By the time you've completed the process, untidy to begin with, reality has changed sufficiently to force you to start your research all over again, and clean up the mess that resulted. When applied to projections of renewable electricity, where innovation rates are high, adoption is growing, wholesale and retail prices are falling, and regulatory environments are changing quickly, Novick's musing takes on a starker dimension: how reliable are even the best estimates of renewable energy growth? And how can potential flaws, if they exist, be corrected?

Techniques to model and forecast energy scenarios were initially developed at the end of the twentieth century to provide insights into the operations of the energy sector [2]. Energy forecasts and models are used to project and assess future electricity demand, natural gas consumption, dispatch decisions, technological change, and energy prices, among other important metrics [3–7]. In recent years, with the electric grid in a state of change, the effectiveness of models to forecast the impacts of growing renewable energy has been increasingly important. However, several studies have found that existing energy models, designed for traditional energy sources, are ill-suited to addressing renewable energy [8]. Most notably, Connolly et al. assessed the ability of 37 major models to analyse integration renewable energy, finding that no energy tool addressed all issues related to integrating renewable energy [9].

To more fully explore these questions and determine the reliability of renewable forecasts, we develop a case study based on one of the tools surveyed by Connolly et al.: the NEMS (National Energy Modelling System) [9]. NEMS is especially important as it is the energy economic model underlying the U.S. EIA's (Energy Information Administration) AEO (*Annual Energy Outlook*), the chief energy forecast of the U.S. Federal Government. Released annually, AEO contains long-term projections of energy supply, demand, and prices in the U.S [10]. AEO projections are relied upon by industry, government, academia, and the public sector for regulatory proceedings, rulemakings, environmental projections, financial

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decisions, creating other energy models, and more. As the Executive Summary of the most recent edition states:

> *Projections in the Annual Energy Outlook … focus on the factors expected to shape U.S. energy markets through 2040. The projections provide a basis for examination and discussion of energy market trends and serve as a starting point for analysis of potential changes in U.S. energy policies, rules, and regulations, as well as the potential role of advanced technologies* [11].

One colleague of ours even refers to it colloquially as "The Bible of energy information."

Indeed, many high-profile regulatory proceedings in the U.S. rely on AEO or NEMS to assess the costs and benefits of regulatory policies. Notably, these include EPA's proposed greenhouse gas regulations for the power sector and regulatory approvals for liquefied natural gas exports [12,13]. One of the major challenges with energy economic models is a lack of transparency: it is usually difficult or impossible for third parties to be able to "independently verify published results" [14]. Unlike other energy models, AEO projections have been published for many years and are well documented, making them a prime candidate to test the effectiveness of energy model projections. Accordingly, multiple studies have assessed the accuracy of EIA's projections for energy demand and generation [15–17]. Of these, only Fischer et al. considered the accuracy of renewable energy projections, finding that electricity utility renewables were consistently over-projected [17]. However, Fischer et al. did not differentiate between renewable energy types, did not examine issues underlying model errors, and was published before large increases in renewable energy began in 2009 [17].

And so in this paper, we ask: is the AEO biased against renewable energy and what might account for the errors? To provide an answer, we compare the historical performance of twelve AEO Reference Case projections made between 2004 and 2014. We expand on previous work by examining technology specific assessments and providing analysis of more recent time frames. We find large technology specific biases as well as an overall under-prediction trend for total non-hydro utility renewables.

We propose, develop and test five hypotheses about the inaccuracy of AEO's projections: challenges modelling state renewable energy mandates, expiration of renewable tax credits are hard to capture, NEMS modelling structure undervalues renewable benefits, inaccurate cost assumptions, and an unjustified biomass co-firing assumption. By exploring these issues in depth in NEMS, we build on previous work by identifying specific errors in one of the most widely used energy models. Our findings have major implications for the reliability of using AEO in regulatory and policymaking in the United States. Finally, we explore potential challenges in renewable energy forecasting that are likely present in the broader energy modelling field.

2. Background and methodology

While the AEO contains multiple scenarios that model the impacts of different economic, technological, and policy assumptions, we only examine projections from the reference case. Other cases are more or less favourable to renewable energy through different technology or policy assumptions. However, AEO's reference case is the most important and widely used – the projections from the reference case have the most influence on policy.

Since 2004, each edition of the AEO has contained reference case projections for generation and capacity for individual renewable technologies for each year until at least 2025. To evaluate the accuracy of these projections, we compare the annual projections against the last year for which actual data is available from the AEO. Due to the time frame of projections chosen for the study, capacity and generation verifications range from 1 to 10 years out. In total, this led to 330 generation verifications and 300 capacity verifications.[2] Notably, AEO output only separates out dedicated and co-firing generation for AEOs 2004–2010 – hence generation verifications for biomass co-firing are only for these years.

After we analyse the projection errors for each technology class, we test five hypotheses about the causes of errors. To test these hypotheses we review the extensive methodology and assumptions documentation provided by EIA for each edition of the AEO.

Finally, it should be noted that there are two editions of the Annual Energy Outlook 2009. The passage of the ARRA (American Recovery and Reinvestment Act) contained a significant number of energy-related policies. This led to EIA re-running NEMS with the effects of the new policies. We measure the projection ability of both: the original outlook is designated as AEO 2009 (pre-ARRA) while the second outlook is labelled as AEO 2009 (post-ARRA).

3. Selecting renewable energy classifications and analysing projections

We selected six distinct renewable technology classifications to evaluate within the AEO:

- Electric power sector wind
- Electric power sector solar photovoltaics
- End-use solar photovoltaics
- Electric power sector biomass
- Biomass co-firing in coal power plants
- Total non-hydro renewables (Total non-hydro RE)

Fig. 1 illustrates individual generation and capacity verifications for five of the six technology classes (biomass co-firing is excluded due to significant over predictions and only a limited number of predictions). Table 1 illustrates average errors for generation and capacity for each technology type during the following periods: 1–3 years, 4–7 years, and 8–10 years.

These results indicate that AEO projections of renewable energy generation and capacity significantly miss actual levels by large amounts in many cases.

3.1. Generation errors

In the short term (1–3 years), on average, AEO reference cases over predict generation from utility solar, biomass, and total renewables. However, average errors for this time frame for utility solar and total renewables are influenced by larger than projected short term generation during AEOs 2004–2007. Very large relative projections for solar PV occurred during these periods due to an EIA assumption for a minimum level of solar deployment as solar was not economically viable at that time.

After AEO 2007, short term errors for these categories decline greatly – utility solar has an average −45% generation under prediction 1–3 years out while total renewables over predictions decrease from an average of 13%–4%. The post-2008 time frame is especially important as total non-hydro renewable generation more than doubled during these years and generation levels more fully reflected growth rates of maturing renewable industries.

[2] AEO output only separates out dedicated and co-firing generation for AEOs 2004–2010 – hence generation verifications for biomass co-firing are only for these years.