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Planning the European power sector transformation: The REmap modelling framework and its insights

Seán Collins[a,b,*], Deger Saygin[c,1], J.P. Deane[a,b], Asami Miketa[c], Laura Gutierrez[c], Brian Ó Gallachóir[a,b], Dolf Gielen[c]

[a] Energy Policy and Modelling Group, MaREI Centre, Environmental Research Institute, University College Cork, Ireland
[b] School of Engineering, University College Cork, Ireland
[c] International Renewable Energy Agency, IITC, Bonn, Germany

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ABSTRACT

IRENA's renewable energy roadmap (REmap) programme enables the assessment of the renewable energy potential at sector and country level for the year 2030 based on a unique methodology that has been applied to 70 countries. This paper presents findings of REmap for the European power sector where the REmap methodology is complemented with a power system dispatch model, called the REpower Europe model. Results show that in 2030 under REmap, gross electricity demand in the EU-28 can be met with a renewable energy share of 50% and a variable renewable energy (VRE) share of 29%. This would achieve a 43% reduction in the EU power sector's carbon dioxide (CO_2) emissions relative to 2005 levels. Although achieving higher renewable electricity shares by 2030 is effective in reducing emissions, significant operational challenges would be encountered to realise the potential identified in REmap. Attention needs to be paid to interconnector congestion, curtailment of VRE and operation of dispatchable generators by power system planners to achieve this potential. While the strength of the REmap approach is transparency that allows engagement with energy planning stakeholders, the key to its effective application is the right balance of model complexity and operational ease. This paper shows the insights that can be gained by leveraging the approach and that valuable policy insights are drawn by using a suite of modelling approaches.

1. Introduction

In early 2014, the European Union (EU) released its 2030 climate and energy framework package. The framework sets three key targets for the year 2030: 1) 40% cut in greenhouse gas (GHG) emissions compared to 1990 levels, 2) at least a 27% share of renewable energy in gross final energy consumption (GFEC), and 3) at least 27% energy savings compared with the business-as-usual scenario [1]. These targets represent an important increase compared to the 20-20-20 targets to be achieved by 2020.

While the proposed targets are EU-wide, the specific role of country, sectors and technologies are not yet determined. In understanding how such regional targets can be operationalized at these levels, the International Renewable Energy Agency's (IRENA) global renewable energy roadmap (REmap) programme with a 2030 outlook is a useful tool [2,3]. In Europe, at the time of writing, 11 Member States that represent more than 80% of EU's total final energy demand are part of IRENA's REmap programme. These countries are Belgium, Cyprus, Denmark, France, Germany, Italy, Poland, Spain, Sweden, the Netherlands and the United Kingdom.[2]

The methodology underpinning the REmap analysis is a relatively simple accounting framework that allows national experts to identify additional renewable energy technology options (called "REmap options") beyond existing renewable energy expansion plans up to 2030 based on current policies and policies under consideration, referred to as the "reference case". To ensure an accurate representation of country-specific challenges, this analytical framework is based on a bottom-up analysis of renewable energy potential in individual

* Corresponding author. Environmental Research Institute, Lee Road, Cork, Ireland.
E-mail address: sean.collins@umail.ucc.ie (S. Collins).
[1] Present address: SHURA Energy Transition Centre, Minerva Han Karakoy, Istanbul, Turkey and Sabanci University, Orta Mah, Tuzla, Istanbul, Turkey.

[2] At the time when the power system model presented in this paper was developed, ten REmap countries (excluding Spain) had a complete REmap analysis. As the model considers two scenarios (a Reference scenario and REmap scenario), a "quick-scan REmap" power system scenario was developed for the remaining 18 countries.

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countries. To date, 70 countries which represent more than 90% of the total global energy demand are participating in IRENA's REmap programme. The unique approach of REmap allows the analysis to be applied to all countries in the world in a comparable way and it provides a transparent way to communicate results with the national experts and other stakeholders.

There are advanced tools available that enable a detailed analysis of the evolution of energy systems, such as long-term energy system optimisation models and integrated assessment models [4]. These models are more sophisticated than the REmap tool and their results were contrasted with REmap by Kempener et al. in Ref. [2]. Their work identified several key insights provided by such long-term modelling tools that are not provided by the REmap approach: the transmission and distribution requirements for higher shares of renewables in the energy system, system constraints, path dependencies or competition for resources that affect both the potential and costs of additional renewable energy deployment. REmap as a tool is better suited to high-level energy system assessment rather than detailed national renewable energy planning and it requires additional checks to compensate for reduced detail on how technologies in an energy system interact with each other. With complementary approaches that overcome its limitations, policy-making can be better informed.

In transitioning to a low-carbon energy system, the power sector will be of paramount importance. The sector is already experiencing a rapid growth in renewable energy capacity in recent years. Worldwide, since 2012, the share of renewable energy in new capacity additions has been increasing and in both 2015 & 2016 renewables were in excess of 50% of total new capacity additions [5]. In the EU, of all the 24.5 GW (GW) power generation capacity added in 2016, 21.1 GW was from renewables [6]. For context, renewables accounted for 405 GW of a total installed generation capacity of 920 GW in the EU in 2016 [6]. However, the sector remains a large emitter of carbon dioxide (CO_2) emissions. When achieving higher shares of renewable energy in the power sector, it is expected that a large share will originate from variable renewable energy (VRE) sources[3] [7–10]. In the EU, the renewable energy share in the power sector reached 28.8% in 2015 out of which little over a fifth was from VRE sources [11]. The generation from these variable sources can be difficult to predict, intermittent and quite location specific. High proportions of VRE sources on the power system, therefore, have a substantial impact on the operation of the power system [12–16]. This leads to challenges with regards to ensuring a reliable and adequate system in the long-term planning of the power sector [4]. This struggle is common to both the REmap tool and to long-term energy system planning models, but for long-term energy planning models, this has been an active area of research with a variety of methodologies having been developed to address this [17,18].

The objective of this paper is to provide policy insights regarding the implications of the power sector technology mix derived from REmap EU analysis for 2030 on the operation of the European power system. For this purpose, an EU power system model[4] (called “The REpower Europe model) has been developed that performs a dedicated hourly operational analysis of the European power sector by modelling economic dispatch assuming full implementation of the renewable energy technology potential according to the REmap findings. These results have been benchmarked against a similar simulation of the model for the reference case for 2030. This process allows for further, more detailed analysis to be performed by exploiting the added value that is brought by using a power system model with high technical and temporal resolution. This complementary approach enables generation of new results that add new insights to REmap findings. In particular, it quantifies levels of curtailment, electricity trade, interconnector congestion, wholesale market price changes, and effects on market clearing (e.g. merit order, marginal unit) and other metrics. The value of these additional insights is in the increased understanding of the robustness of a transitional low carbon electricity sector and in identifying challenges and operational concerns which may accompany that transition. While this analysis draws conclusions for policy making by linking two complementary approaches, it also thoroughly compares them by discussing their strengths and weaknesses. This is particularly important so as to gain more insight into the right balance of model complexity and operational ease.

The large synchronously interconnected nature of the European power system coupled with increased variability on the supply side will lead to the increased importance of interconnector flow in efficient and cost-effective power system operation. In a power system with high penetrations of VRE, the short-term ability to export and import electricity as required to mitigate the negative impacts of variability is an important consideration. This required the detailed REmap results to be analysed within the context of a wider European electricity model, even though the REmap analysis has only been completed for ten countries. In order to draw conclusions for the entire region, the REmap analysis was expanded to cover the remaining 18 EU Member States by developing an accelerated renewable energy scenario that builds on European Commission's EU Reference Scenario [19] (hereafter referred to as the EU Reference Scenario) which is a projection of where the current set of policies coupled with market trends are likely to lead.

The rest of the paper is structured as follows: Section 2 introduces and describes the policy and modelling tools informing this analysis. Section 3 describes the methodology underpinning this analysis. Section 4 provides a detailed overview of the results of this analysis, providing a broad assessment of the power system developed under the REmap tool. Section 5 forms a discussion of the key results and the strengths and weaknesses of the REmap tool as well as the complementary model used for power dispatch. Section 6 synthesises the conclusions drawn in this work.

2. Policy and modelling tools

This section explains the models and data sources that were used for the analysis. They include IRENA's REmap tool, PLEXOS Integrated Energy Model and the PRIMES model from which the EU Reference Scenario is derived that is used by European Commission to inform policy development. In this study, the installed capacity mixes and demand for power generation from the REmap analysis for 10 EU countries were used as an input. For the installed capacity mixes and demand for the remaining 18 EU countries, the EU Reference Scenario 2016 was used. This data from the REmap tool and the EU Reference Scenario are then used as input for the subsequent analysis of power systems operation using a dispatch model, the REpower Europe model, built using PLEXOS.

2.1. REmap tool

REmap is a tool that helps to define renewable energy technology options across all energy sectors for decision-makers to consider. The process is to first collect data from countries about their national energy plans and goals, and the next step is to produce a national baseline for renewable energy deployment for the period between 2010 and 2030. This is called the Reference Case. Subsequently, technology pathways that reap the rewards of the reasonably optimistic potential of renewable energy technologies beyond the Reference Case are prepared, these are the REmap options. Reference Case and REmap options combined yield the “REmap” case. This process is illustrated in Fig. 1. REmap options are customised for specific countries and sectors and aim to close an important knowledge gap for many countries by helping policymakers gain a clearer understanding of the opportunities that lie

[3] VRE generation sources discussed in the context of this work consist of wind and solar PV generation only, which have far more variability in the short term than other renewable modes of generation such as hydro power.

[4] Swiss and Norwegian power systems are also represented.