Energy Policy 116 (2018) 112–126

Contents lists available at ScienceDirect

Energy Policy

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

How can the renewables targets be reached cost-effectively? Policy options for the development of renewables and the transmission grid[☆]

Anne Held[a,*], Mario Ragwitz[a], Frank Sensfuß[a], Gustav Resch[b], Luis Olmos[c], Andrés Ramos[c], Michel Rivier[c]

[a] Fraunhofer Institute for System and Innovations Research ISI, Breslauer Strasse 48, 76139 Karlsruhe, Germany
[b] Energy Economics Group (EEG), Institute of Energy Systems and Electric Drives Vienna University of Technology, Gusshausstrasse 25-29/370-3, 1040 Vienna, Austria
[c] Comillas Pontifical University, ICAI School of Engineering - Institute for Research in Technology, C/ Santa Cruz de Marcenado, 26, 28015 Madrid, Spain

ARTICLE INFO

Keywords:
Renewables development
Support policies
Transmission grid development
Power system

ABSTRACT

Increasing the share of renewable energy sources in the electricity sector (RES-E) contributes to achieving the European energy and climate targets including a 27% share of renewables in final energy consumption by 2030. We assess the future costs of the power sector for different RES-target levels and support schemes including generation costs, system operation costs and transmission grid development costs based on three power sector models. The results show similar power system costs for different target levels. RES-E shares below 70% involve limited infrastructure costs that are below 2.6% of the overall system costs. The impacts of the modelled RES-E policies, an EU quota and national feed-in premiums on transmission costs are ambiguous: Contrary to expectations, the costs of transmission network development under quota obligations are lower than under technology-specific feed-in premiums for RES-E penetration levels up to 50%. The drivers of transmission costs include not only a concentration of renewable capacity, but also the exact location of RES-E capacity with respect to existing power plants and the strength of the existing infrastructure. Quota obligations lead to higher grid costs than feed-in premiums if the RES-E share amounts to 70% due to the stronger regional concentration of RES power plants.

1. Introduction

There are various pathways ensuring the transition to a low carbon economy that focus on different technology options. The increased use of renewable energy sources (RES) plays a major role in achieving low-carbon targets. When considering different technology pathways towards a future low-carbon energy system, the associated cost aspects play a crucial role and require a sound knowledge of the total energy system costs. Accordingly, the European Council has agreed to increase the share of RES in final energy consumption to 27% by 2030 as part of the 2030 framework for energy and climate policies (European Council, 2014). The question arises whether higher shares of RES than the envisaged 27% would make sense from an economic viewpoint given the fact that the European Commission's impact assessment already estimates the RES-share at 26.4%, triggered only by the 40% greenhouse gas emission reduction target and without a dedicated RES-target (European Commission, 2014b). Both this impact assessment as well as a further in-depth analysis (Duscha et al., 2016, 2014) have shown that a higher RES share, such as 30%, can lead to higher macro-economic benefits compared to a RES-share of 27%. In these studies, the positive macro-economic effects result mainly from higher investments and lower use of fossil (imported) fuels, whereas potential negative impulses come from higher consumer bills driven by the additional costs of renewable energy. To date, the power sector accounts for the highest RES-investments as well as the highest additional costs of these technologies. Due to the rapid learning taking place in key RES-E technologies, their cost disadvantage diminishes quickly and allows higher capacity additions without compromising the macro-economic benefits. Therefore, our analysis concentrates on the impact of different RES-E pathways on the system costs of the electricity sector considering generation and transmission. Due to the prominent role of the power sector in decarbonising the economy, the issue of estimating the future costs of the power sector by 2030 for different RES-target levels has risen up the agenda. Relevant cost components include the conversion costs of the technologies used as well as the costs occurring due to the integration of variable renewable electricity (RES-E) into the power

---

[☆] Topic: Energy Conversion, Transportation/Transmission, and Storage.
[*] Corresponding author.
E-mail address: anne.held@isi.fraunhofer.de (A. Held).

https://doi.org/10.1016/j.enpol.2018.01.025
Received 12 June 2017; Received in revised form 4 December 2017; Accepted 11 January 2018

system, including the need for the grid infrastructure and storage options. Accordingly, energy system models face new challenges due to the increasing share of variable RES-E and flexible demand profiles and require a higher spatial and temporal resolution (see e.g. Pfenninger et al., 2014). However, as pointed out by (Després et al., 2015), there is a lack of models combining long-term investment decisions in the power sector with system operation and the development and the use of the grid infrastructure. Existing long-term energy models are often characterised by a coarse spatial and temporal resolution and a systemic view (Després et al., 2015). The reasons for this are limited data availability – representing the grid is only useful if regionally disaggregated supply and demand data are available (Després et al., 2015) – and the computational tractability of optimisation models (Pfenninger et al., 2014). One model used by (Haller et al., 2012), the LIMES-EU$^+$ model, has been applied to develop long-term decarbonisation scenarios for the EU and MENA-region, taking into account short-term dynamics and spatial aspects including the development of grid infrastructure. However, its temporal resolution based on characteristic time slices of 6 h remains too coarse to represent very short time scales. Although the authors do not specify how grid infrastructure is represented in terms of geographical resolution, it seems that grid extension options follow a simplified approach reflecting the transmission of electricity between but not within countries based on net transfer capacities. This simplification and the low geographical resolution involve considerable uncertainties assuming standard distances between regions or countries. In reality, interconnections between regions tend to cover much smaller distances, in particular for early reinforcements and national reinforcements.

Taking a closer look at existing studies on the development of the European transmission grid, it becomes clear that few have analysed the impact on network costs of the location and type of RES generation considered in the system development. Much of the work on transmission network development in Europe concludes that the CO_2 emission reduction achieved (Egerer et al., 2015; Holz and Hirschhausen, 2013), and the degree of RES penetration (Couckuyt et al., 2015; European Commission, 2011; Fürsch et al., 2013; Gaxiola, 2012; Holz and Hirschhausen, 2013) are major drivers of transmission development costs, and contribute to increasing them. Some of them even conclude that the type of clean technologies deployed (RES generation, energy efficiency) and their geographical location, or distribution in the system, barely affect transmission costs (Egerer et al., 2015; Holz and Hirschhausen, 2013). However, some other studies recognise the clear impact of the geographical distribution of RES generation on network (transmission and/or distribution) costs. Thus, according to (Couckuyt et al., 2015) and (Greenpeace, 2011), network development costs are significantly larger when RES generation is deployed following a centralized approach than when it is widely spread.

Concerning the formulation of the transmission network development problem, some of the previous studies represent the network in Europe in detail, but only a reduced set of operating situations, see (ECF, 2010; Egerer et al., 2015; Frías et al., 2013; Holz and Hirschhausen, 2013). In other studies, a wide range of operating situations is taken into account, but the network representation is coarse, since only one node is used to represent each country, see (ECF, 2010; European Commission, 2011; Holz and Hirschhausen, 2013). Similarly, (Pleßmann and Blechinger, 2017) realise a joint optimisation of generation, storage and transmission to analyse European power supply in the context of reaching the EU greenhouse gas emissions reduction target by 2050, but their representation of the grid infrastructure with only 18 regions remains sketchy.

Some studies feature a detailed network model and a wide range of system operating conditions. However, in most of them, the computed network reinforcements are not optimal, because the benefits produced by potential reinforcements are assessed by including them only sequentially in the network and not by jointly optimising generation and transmission over the entire time horizon. This leads to the computation of reasonable, though largely suboptimal, reinforcements, as in (Couckuyt et al., 2015; ENTSO-e, 2014; Greenpeace, 2011). The reason for suboptimal results is the use of heuristic algorithms in large problems if not all the possible solutions to the problem have been explored. This is typically the case if the development of the network is determined by sequentially considering potential reinforcements (Banez Chicharro et al., 2017). An exception to this may be the work in (Hagspiel et al., 2014), where the development of generation and transmission in Europe is jointly and centrally optimised. However, this optimisation over all EU Member States does not respect existing political constraints and regulations such as the national RES-targets required by Directive 2009/28/EC (The European Parliament and the Council of the European Union, 2009). The approach followed in the analysis described here achieves an appropriate balance between the level of detail considered in the representation of both the grid and the variability in system operating conditions. At the same time, the transmission expansion planning problem is solved through the application of classical optimisation techniques. This should lead to the computation of the optimal development of the grid, provided a valid solution is found by the algorithm.

Our analysis uses two scenarios to compare the overall costs of RES development including generation costs, system integration costs and infrastructure-related costs. One scenario applies a technology-neutral quota obligation to achieve low-cost RES development. The other scenario applies technology-specific feed-in premiums for a more balanced RES development. In this context, we expect the costs related to the required grid infrastructure to be higher for RES-scenarios with stronger regional concentration. A Europe-wide quota system should lead to higher regional concentration because of the technology and EU-wide optimisation and therefore to higher infrastructure costs than a technology-specific feed-in premium. The technology-specific feed-in premium incentivises a portfolio of RES technologies with a more even distribution of RES capacity across all EU MS. We explore whether technology-specific feed-in premiums imply lower grid costs compared to a European-wide technology-neutral quota system, as is often supposed, and apply a modelling approach with a high temporal and geographical resolution to reflect the impact of renewables support policies on system and grid costs.

2. Methodology

For the model-based approach, we combine three different energy sector models. RES-deployment pathways are modelled using the simulation model Green-X in order to reflect the impact of energy policy instruments on RES-deployment and the related costs and benefits for EU-countries. These RES-deployment pathways are then fed into the power sector model Enertile in order to analyse the development of the power sector as a whole. A comprehensive optimisation of the European power sector until 2050 is carried out including the detailed modelling of renewable generation data with high spatial and temporal resolution. Capacity planning for conventional power plants, the operation of the power system and grid extension, reinforcement and management are taken into account. Results of Enertile are then included in a second modelling iteration of renewables development in Green-X so that both models produce consistent output. In the final stage, the grid model TEPES uses the power generation results in order to assess transmission grid-related issues of RES-E integration in more detail. The system network development and operating costs produced by TEPES are considered together with the data for cost components related to electricity generation from Enertile to produce an estimate of the total RES-integration costs associated with the different RES generation strategies and RES targets analysed. The results produced by TEPES were not iterated with Enertile due to the extensive effort this would involve and the low additional benefit expected. Since generation/storage costs are normally much higher than network costs, it is unlikely that considering the network development costs associated with the installation