Energy Policy 59 (2013) 904–913

Contents lists available at SciVerse ScienceDirect

Energy Policy

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

# Assessment of the required share for a stable EU electricity supply until 2050 ☆

Wietze Lise [a,b,*], Jeroen van der Laan [c,d], Frans Nieuwenhout [e], Koen Rademaekers [c,d]

[a] AF Mercados EMI, Ankara, Turkey
[b] ECORYS Research and Consulting, Ankara, Turkey
[c] Energy & Environment unit, ECORYS, Rotterdam, the Netherlands
[d] Triple E Consulting, Rotterdam, the Netherlands
[e] Energy-Research Center of the Netherlands, ECN, Amsterdam, the Netherlands

## HIGHLIGHTS

- Assessment of costs for higher shares of intermittent generation.
- Quantifiable indicators of stable supply, namely the share of flexible supply and the balancing need.
- Grid costs are considerable for higher share of intermittent generation.

## ARTICLE INFO

*Article history:*
Received 12 April 2012
Accepted 2 April 2013
Available online 1 May 2013

*Keywords:*
Energy Roadmap 2050
European grids
Intermittent supply

## ABSTRACT

Power system balancing will become increasingly important to secure a reliable European energy supply, as the share of intermittent supply increases (e.g. variable generation from wind and solar PV). This paper shows, in a quantitative way, the limitations of relying exclusively on flexibility in generation as the future shares of intermittent supply increase. Literature and data on intermittent supply and existing scenarios are reviewed. Costs related to increasing shares of intermittent supply are assessed. Quantifiable indicators relevant for electricity systems with a high share of intermittent supply are developed, namely (a) flexible supply (generation units that can quickly change output); (b) balancing need (which measures the needed flexibility of the power system as the difference between peak and off-peak residual demand (net of intermittent supply)). There is an externality of increasing the share of intermittent supply by increasing the power system balancing costs. If the cost of integrating intermittent generation was to be limited to about 25 billion EUR per year, which is an addition of 24% per unit intermittent generation cost, the intermittent supply share cannot reach more than 40% in the European power market. The final choice of an acceptable cost increase will be a political choice.



## 1. Introduction

After Germany, Japan is also considering the phase out of nuclear energy. Nuclear is to be fully phased out and replaced with renewable energy within the next 30 years (Cbsnews, 2012). This paper intends to show the challenges ahead to make such a transition possible and estimates the additional cost to integrate renewable energy into the grid until 2050 in Europe.

Europe is facing several major energy challenges, including the depletion of indigenous energy sources, increasing fuel costs and the threat of energy supply disruptions. At the same time, it also recognises the need to reduce greenhouse gas emissions and, consequently, the consumption of fossil fuel generated electricity. Hence, a balance has to be found among greenhouse gas emission mitigation, security of supply and affordability of electricity. On top of that, nuclear energy is becoming less popular as a reliable source has electricity generation, making the choice for carbon free technologies more limited. It will be difficult to strike a balance between these challenges, without firm changes in policy-making. Especially, when taking the long term into account, which is the purpose of this paper. Therefore, a major shift in energy policy is needed, where renewable energy will start playing an increasingly larger role.

With larger shares of renewable energy in the generation mix, power system balancing will become increasingly more important to

* Corresponding author. Tel.: +90 312 385 9354; fax: +90 312 354 6927.
*E-mail addresses:* wietze.lise@afconsult.com, wietze.lise@gmail.com (W. Lise).

☆We thank the European Commission (DG Energy) for funding this project. However, opinions and conclusions expressed are solely the author's.

0301-4215/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2013.04.006

securing a reliable European energy supply. This will also become a significant challenge, because the most popular renewable energy technologies, e.g. wind and solar PV, follow weather patterns, rather than demand, and are also known as intermittent supply.

According to EWEA (2009), 332 GW of new electricity capacity needs to be built to replace ageing power plants over the next 10–15 years, whereas ENTSOE (2010) projects a capacity increase of 237–277 GW over the period 2011–2020. Directive 2009/28/EC on the renewable energy implementation, aims to increase the share of electricity generated from renewables in the 27 countries of the European Union (EU-27) from 8.6% in 2005 to 20% by 2020. In order to be able to deploy renewable energy sources further, some (non-cost) barriers need to be removed, like administrative hurdles and barriers to grid connections (Ecorys and EU, 2008)). In particular, there is a clear need to support the integration of intermittent supply into the transmission and distribution grid, this can involve greater use of energy storage systems (European Union 2009). Moreover, in the intermediate term to 2030 (but more important for the longer term to 2050), significant increases of supply can be achieved by intermittent supply (IEA, 2011). Intermittent supply has a high potential in the European energy mix (in excess of 30%) when new grid infrastructure technologies and operational approaches are in place (DLR, 2008; Ecofys, 2008; ECF, 2010a, 2010b, 2010c, 2010d, 2010e, 2010f).

Of all the renewable electricity-generating technologies, onshore wind is the largest contributor to total installed capacity. As such, the role of onshore wind will be crucial for achieving the share of renewable energy supply (RES) needed by 2020 (EWEA, 2009). In 2010, natural gas was the largest contributor of new generation capacity (51% or 28 GW), followed by PV (22% or 12.3 GW) and wind (16.7%, or 9.3 GW).[1]

Along with the increase in onshore wind power generation (and RES in general), comes an increasing need to improve the energy infrastructure to ensure an efficient accommodation of this new intermittent supply (EWIS, 2010). Intermittent supply cannot be stored at a large scale in an economically viable way except for the use of pumped hydropower storage. Beyond a certain share of installed capacity, intermittent supply technologies pose a significant challenge for real time power system balancing, where, in addition to demand side variation, there is also supply side variation (ENTSOE, 2011).

When linked to electricity generation technologies, we define stable electricity supply in this paper as generation derived from hydropower, fossil fuel and nuclear power plants. This makes stable electricity supply equivalent to total generation capacity minus intermittent supply. To assess the role of stable electricity supply until 2050 in the EU, this paper aims at identifying the requirements and preconditions for reliable integration of large(-r) shares of intermittent supply, from a load following (or balancing[2]) perspective, into EU power systems over mid- and long-term future perspectives (2030 and 2050).

Various studies have been undertaken to address this issue, e.g. Ambec and Crampes (2010), European Commission (2011), Klessmann et al. (2011), Perez-Arriaga and Batlle (2012). Among them, the EU Energy Roadmap 2050 (European Commission, 2011) is a very comprehensive project. This EU Energy Roadmap is driven by the need for energy security, sustainability and competitiveness given the changing global energy context. The mission of the EU Energy Roadmap 2050 is to provide a practical, independent and objective analysis of pathways to achieve a low-carbon economy in Europe, in line with the energy security, environmental and economic goals of the European Union. This is consistent with the established objectives of EU energy policy – sustainability, energy security and competitiveness – with a focus on cost-effective decarbonisation.

The main objective of this study is to show, in a quantitative way, the relative role of different sources of flexibility, including flexible generation, in guaranteeing system stability under various future shares of intermittent supply. The main activity carried out in this study is the construction of merit-order curves of flexibility measures to accommodate intermittent supply. These are based on estimates of the extent of adaptation measures needed and their costs. These are presented graphically, with the share of stable supply and the balancing need shown as a function of the share of intermittent supply. Finally, the relationship between stable supply, net balancing need, share of intermittent supply cost and balancing cost has also been presented graphically.

The outline of the paper is as follows. The next section provides an overview of well-documented and official scenarios to reach a nearly carbon neutral power sector by 2050 and a regional division of Europe is proposed which is relevant for the power sector. Section 3 presents the cost adaptation model, which is used to estimate the power system adaptation costs under increased shares of intermittent supply. Section 4 contains the main analysis, consisting of (1) a presentation of the need to balance the power system, (2) derivation of adaptation measures and costs, (3) regression link between intermittent supply and two measures of stable supply and (4) the cost drivers under higher shares of intermittent supply. The final section concludes.

## 2. Scenarios for a carbon neutral power sector in 2050

The most relevant, and comparable, existing scenarios for the intermediate (2030) and long (2050) term, on different shares of intermittent supply in the EU energy mix and integration, are:

- Scenarios from the on-going IRENE-40 project in Europe (five scenarios) (IRENE-40, 2011);
- Pathways from the Energy Roadmap 2050 study of the European Climate Foundation (four scenarios with different shares of RES) (ECF, 2010a, 2010b, 2010c, 2010d, 2010e, 2010f);
- Scenarios from the Power Choices study of Eurelectric (two scenarios) (Eurelectric, 2009; Ecorys, 2010).

These three sets of scenarios are all credible storylines and they are designed to reach a decarbonised economy by 2050 if sufficient effort is taken. However, under a continuation of the current policy (Baseline or BAU) this will not be achieved. Table 1 presents an overview of the three sets of the long-term electricity scenarios (ECF, Eurelectric and IRENE-40).

Fig. 1 compares the scenarios in terms of demand growth, showing that the scenarios are all quite close to each other, with the exception of the IRENE-40 EFF scenario.

The comparison in Fig. 1 shows that the IRENE-40 BAU scenario is quite close to Eurelectric's Baseline 2009 but also to the ECF Baseline in terms of demand growth. These three baseline scenarios all envision that the current (policy) trends continue, and a substantial reduction in greenhouse gas emissions will not be achieved. The IRENE-40 CCS scenario is close to the Eurelectric Power Choices scenario and the ECF 40% RES scenario, in terms of the RES share. The energy efficiency (EE) scenario is a new scenario, with a substantially lower demand for electricity as compared to all ECF pathways and Eurelectric scenarios. Nevertheless, this scenario is close to the ECF 60% RES scenario in terms

[1] See http://www.icis.com/heren/articles/2011/01/31/9430970/eus-renewable-growth-falls-short-in-2010.html.

[2] The issue at stake is balancing supply and demand at different time scales from seconds to seasons. However, in power system analysis the term 'balancing' is used for matching expected generation with forecasted demand shortly before real time (typically one hour to 15 min). Therefore the term load-following is used here although 'residual load-following' would be more correct.