

The role of demand and vRES flexibility in carbon-neutral power systems: Insights from Portugal and Spain in prospective 2050 scenarios

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Abstract— The goal of a carbon-neutral society by 2050 is speeding up the integration of variable renewable energy sources (vRES) in European power systems. For the expected levels of vRES, the adaptation of the demand will be crucial to manage the stochastic behaviour of these technologies. This work evaluates the impact of four prospective 2050 energy mix scenarios in the Iberian electricity market. All scenarios consider near 100% vRES shares. Scenarios that incentivize demand flexibility (S2 and S4) result in the lowest wholesale prices and costs for society. Peak load reduction using demand response occurred in the two scenarios (S1 and S3) with low demand flexibility and high share of renewable generation. S3 is the most unstable leading to the higher wholesale prices. The results highlight that an equilibrium between demand flexibility and investments in the generation side is essential for reducing costs and ensuring stability.

Keywords— Active demand, Carbon-neutrality, Electrification, Flexibility, Variable renewable energy sources, Wholesale prices.

I. INTRODUCTION

The participation of vRES in power systems has been increasing to accomplish the target of a carbon-neutral society by 2050. Indeed, some European countries already plan to be carbon-neutral by 2035. Portugal and Spain's National Energy and Climate Plans for 2030 (NECPs) already expect vRES, mainly onshore wind and solar photovoltaic (PV), as the main energy providers by 2030 [1-3]. So, their power sector will be mostly satisfied by renewable energy sources (RES). However, the power sector is only a small component of the used energy. Electrification of industry and transport sectors is important to achieve carbon neutrality, as reported in 2030 NECPs. Furthermore, sector coupling with the heat sector and replacing gas by hydrogen (H₂) can be another important aspect to achieve carbon neutrality, reduce external energy dependency, and adjust to vRES production [4-6]. For large-scale integration of vRES, their stochastic behaviour and reduced dispatchability will need the adaptation of the demand to avoid vRES curtailments and load shedding events. Against this

background, demand and vRES flexibility is the key to future carbon-neutral, stable, and affordable energy systems by 2050. So, decarbonisation and sector coupling shall be supported by measures that incentivize demand and vRES flexibility, such as new market designs [7-10].

Traditional electricity markets, primarily developed during an era dominated by fully dispatchable conventional power technologies, operate on a marginal-cost pricing model to efficiently allocate resources, incentivize technological investments and minimize costs [11]. However, this market mechanism becomes ineffective in power systems with high shares of vRES with low marginal costs. Despite the environmental advantages of large-scale vRES integration, their inherent variability can lead to periods with excess energy in the market, driving electricity prices to zero or even negative values, based on the "merit order effect" [9-12]. While this price reduction benefits consumers, at certain vRES penetration levels, it also diminishes the market-based remuneration of (all) power producers, a challenge commonly referred to as the "self-cannibalization effect" [12]. This, in turn, reduces incentives for investment in new capacity, potentially hindering the ambitious RES targets for the coming decades in Europe. Conversely, when demand is high and vRES generation is low, energy prices highly increase. Unexpected events, such as the European energy crisis, have further amplified price volatility, raising significant concerns regarding the existing market design, investment risks/de-risking, and consumer protection [13, 14]. Against this background, this work uses an integrated daily trading framework combining different tools to simulate four different prospective 2050 scenarios in the Iberian electricity market (MIBEL). Each scenario assumes different assumptions on the demand flexibility and power generation. The Iberian electricity market (MIBEL). Some changes to actual market designs and rules to better integrate vRES and demand flexibility are proposed in the simulation framework .