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Effects of renewables penetration on the security of Portuguese electricity supply

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HIGHLIGHTS

- We assess the importance of the electricity sector in energy security in Portugal.
- We compare energy security indicators for 2004 and 2011.
- Strong wind penetration has an important role on the country energy security.
- Infrastructure is the weaker component in electricity sector supply chain.

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ABSTRACT

The increase of renewables in power sector, together with the increase of their electricity share in final energy consumption, is changing our perception about energy security with diverse and contradictory statements. The Portuguese security of electricity supply is analyzed in this study by comparing selected indicators for 2 years before and after the high increase of onshore wind since 2005. Our goal is to find how the security of electricity supply was impacted by the penetration of renewables, taking a supply chain approach. Our analysis highlights that the penetration of renewables has decreased the energy dependence of the power sector by more than 20% between 2004 and 2011, while risks related to the concentration of natural gas suppliers and to the still-high share of fossil fuels suffering from price volatility are discussed. We observed a significant improvement in power interconnections with Spain, as well as an increase of the de-rated generation capacity margin, allowing proper management of renewable power intermittency if necessary, thereby improving power security. Although the share of intermittent renewables almost quadrupled in total installed capacity between those years, the indicators reveal an improvement in the quality of transport and distribution when delivering electricity to end-users. Although electricity prices increased, mainly due to taxes, the lack of energy efficiency is an aspect deserving improvement to alleviate the pressure on electricity security, mainly at high peak demands.

1. Introduction

The current global challenges concerning the availability, diversity and accessibility of energy resources reinforce how vital it is to assure and maintain the supply and demand of adequate quantities of affordable and environmentally sustainable energy services [1]. Energy security is the ability of an economy to provide sufficient, affordable and environmentally sustainable energy services to maintain a maximum welfare state, even in the presence of confounding factors [2]. Nevertheless, different definitions have been used [3–5] and have usually been adjusted by countries or international organizations depending on their national priorities and concerns [5]. An extensive review of past studies on energy security indicators has been presented, e.g., [6].

Energy security is one of the main goals of energy policy [3] and one of the three pillars of the European Union (EU) energy policy [7,8]. An important aspect of energy security is its environmental component. The use and consumption of energy can affect the environment in a variety of ways and magnitudes of effects. The combustion of fossil fuels to produce energy is the main cause of climate change due to the emission of greenhouse gases (GHG). Consequently, the security of the energy supply and climate change mitigation are key concerns for policy makers and important dimensions of the long-term quest for a sustainable global

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Nomenclature

Abbreviations

AF	availability factor
CF	capacity factor
EU	European Union
GDP	gross domestic product
GHG	greenhouse gas
HPI	hydroelectric production index
RES	renewable energy source
RES-E	renewable energy source for electricity production
TPE	total primary energy
UK	United Kingdom
WPI	wind production index

Variables and parameters

APD	annual peak demand
CAIDI	customer average duration index
CI	customer interruptions
CM	gross capacity margin
CS	customer served
CO_2e	equivalent carbon dioxide
D	demand
drCM	de-rated capacity margin
EB	energy bill
EC	electricity consumption
EE	GHG emissions per unit of electricity
Emi	GHG emissions from electricity production
EP	electricity prices
GJ	gigajoule (10^9)
GVA	gross value added
GW	gigawatt (10^9)
HHI	Herfindahl–Hirschman index
HPC	household private consumption
I	intensity
IC	import capacity
ID	import dependency
ip	import price
MW	megawatt (10^6)
PE_{RES}	renewable energy sources on primary energy
r	total reserves
s_RES_{cap}	share of RES capacity
$s\_RES_{cap-int}$	share of intermittent RES capacity
SAIDI	system average interruption duration index
SAIFI	system average interruption frequency index
SEC	sectorial electricity consumption
SS	strategic stock
TIPC	total installed power capacity
TEC	total energy consumption to generate electricity plus net imports
TEP	total electricity production
TJ	terajoule (10^{12})
UIR	utilization of interconnection rate

Subscripts and superscripts

a	sector
c	company
cap	capacity
e	electricity or natural gas
elc	electricity
f	fuel
i	suppliers
imp	import
l	peak or base load
MC	market concentration
N	number of suppliers
prod	production
sup	supply
t	technology
X	number of companies
y	resources
Z	number of technologies

energy system [9]. These aspects are evidenced in the "Energy Trilemma" defined by the World Energy Council that suggests meeting, at the same time, the challenges of growing energy demand or energy security, the protection of the environment and the development of a socially equitable energy system [10]. Renewable energy sources (RES) appear to be a symbiotic option to achieve climate change mitigation and energy security goals at the same time [11].

The power sector is a fine example of these linkages, as the consumption of fossil fuels for electricity production exacerbates climate change and lowers energy security, due, respectively to the release of high quantities of GHG emissions from fossil fuel combustion to the atmosphere and the increase of imports of primary energy, when this applies. Carbon capture and sequestration technology may change the former. The power sector also plays an indirect but important role in the energy security of the overall energy system because electricity can be used to produce alternative fuels (e.g., biofuels and hydrogen) as substitutes for conventional fossil fuels.

The most secure way to minimize energy supply risk is to maximize domestically controllable energy supplies [11,12]. Because renewables are endogenous resources, increasing their share in the energy mix will reduce dependence on imported fossil fuels (such as natural gas), often from unstable regions, and prevent the impacts from price volatility that have characterized the energy commodities markets. Moreover, decentralized power production from renewables decreases the risk of disruption inherent to energy transport, as well as cross-border transport losses. However, an increased share of RES, particularly wind, hydro and photovoltaic sources, has some drawbacks such as intermittency and seasonal and daily variations [13], which require a reserve capacity based on controllable sources, such as large hydro stations with pump storage, fossil fuels such as natural gas and coal or falling back on energy storage plants.

RESs have greatly increased their contribution to EU energy consumption, growing approximately 4% per year from 2000 to 2011 [14], mainly due to increased electricity production from biomass, wind and photovoltaic. Hydropower is the most important renewable energy source for electricity production (RES-E) in Europe, accounting for approximately 63% of the RES gross electricity production in 2011 [14]. Wind and photovoltaic power have also experienced significant increases since 2000 with a net growth of 82.4 GW and 47.4 GW [15], respectively, and therefore have begun to be consolidated in the European energy mixes.

Historically, Portugal has had high foreign energy dependence, but from 2005 onwards, it experienced a significant increase of endogenous energy sources use, almost doubling its power capacity from 2004 to 2011, including a 700% increase in wind power [16]. Portugal has the third-highest penetration of wind power in electricity generation among the EU-27 countries [15].

Beside transportation, the Portuguese power sector is one of the main contributors to GHG emissions, representing 21% in the year