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Long term outlook of primary energy consumption of the Italian thermoelectric sector: Impact of fuel and carbon prices

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ABSTRACT

The aim of the present research is to evaluate future primary energy consumption in the Italian thermoelectric sector. Despite its importance in the European context, researches addressing the primary energy consumption in the Italian power sector are not available in the literature. Therefore, to bridge this gap, a detailed representation of the power generation sector is proposed by modeling each individual thermal power station by considering its main features (i.e. maximum power, minimum stable level, efficiency, etc.), in order to estimate the future energy balances and the trend of power prices. An evolution of the generation fleet is designed according to available information from different sources and a simulation based on plant by plant competition is performed up to the year 2022. The impact of different fuel and carbon price scenarios is analyzed in terms of primary energy consumption.

The analysis has shown that a high level of CO_2 prices does not foster the coal to gas transition, but it causes a relevant increase of power prices. In fact in the best case, it is detected that in 2022, for a carbon price of 30 €/t and a "base" price scenario for fossil fuels, there is a decrease of coal consumption of ~5.6% and an increase of power price of +19% with respect to the base carbon prices.

Therefore, it follows that final users are penalized, because they are expected to pay much higher electricity bills to obtain a modest reduction of coal consumption and carbon emissions.

1. Introduction

The study of the evolution of the energy system of a country is of fundamental importance for its development, because the decisions about energy policies cause long period effects, therefore it is of paramount importance to assess all the available options in order to have a clear perception of the possible impacts.

Due to the strategic relevance of such a kind of analysis and to the variety of methodologies that can be applied, the study of evolution of energy systems attracts the interest of many researchers all around the world.

Some authors decided to compare different methodologies and tools utilized to perform energy analysis aimed at different objectives (e.g. global vs. local, general vs. sectorial, etc).

For example, Connolly et al. [1] dedicated their attention to the simulation of energy systems with a relevant share of renewables and performed a review study of the available computer tools.

Whereas, Foley et al. [2] and Ventosa et al. [3] focused their interest on the modeling of the electricity sector. They performed review studies, providing an overview of electricity systems modeling techniques, discussing a number of key proprietary models used in the USA and Europe. A classification of different typologies of models based on their relevant attributes is also proposed in Ref. [3].

The modeling of energy consumption in the residential sector was the topic of a research conducted by Swan and Ugursal [4], who performed a review of the relevant literature on the topic. They separated the modeling approach in two main categories: "top down" and "bottom up". The top-down approach treats the residential sector as an energy sink by utilizing historical aggregate of energy values and regressing the energy consumption of the housing stock versus relevant explaining variables. Instead, the bottom-up approach extrapolates the estimated energy consumption of a representative set of individual houses to regional and national levels, and it can be based on a statistical or engineering method. This concept can be easily extended to other classes of energy consumers.

Other authors performed researchers on the modeling of carbon emissions linked to the operations of energy systems.

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Nomenclature

C	cost, €/MWh$_t$
CE	quota of variable cost due to emissions, €/MWh$_e$
CF	quota of variable cost due to fuel, €/MWh$_e$
D	power demand, MW
F	power flow, MW
G	generation, TWh
IMP	import of electricity, TWh
M	number of import/export countries
N	number of power plants
ND	net demand, TWh
P	power, MW
T	total time of the simulation, h
TMS	thermal market space, TWh
U	power plant state variable (i.e. on or off)
VC	variable cost, €/MWh$_e$
VOM	variable operating and maintenance cost, €/MWh$_e$

Greek symbols

ε	emission factor, t/MWh$_t$
η	power plant efficiency, MWh$_e$/MWh$_t$

Subscripts

down	refers to downtime
i	power unit index
H	hydro
max	maximum
min	minimum
off	switched off
on	switched on
RES	renewable energy sources
t	time index
up	refers to uptime

For example, Hughes and Strachan [5] performed a review of UK and international low carbon scenario studies, whereas Lau et al. [6] proposed different approaches to estimate carbon emissions in the electricity sector.

Another relevant group of researchers devoted its attention to the development of "regional based" studies, where they analyze the current situation and future development of the energy system of a specific area (i.e. region, country, group of countries, etc.), with reference to a specific sector (i.e. residential, industrial, power, etc.) or in global terms, by taking into account all the main sectors at the same time. Two examples are reported in Refs. [7,8].

In particular, a quantitative analysis of the technological, economic and environmental impacts of different supply policies and demand assumptions on the future Japanese electricity system is reported in Ref. [7] and a study of the present conditions and possible developments of the Romanian electricity system is shown in Ref. [8].

Different authors focused their attention on the utilization of the software Energy Plan [9] to perform simulations for a variety of energy systems in different countries all around the world, such as Hong Kong [10], Hungary [11], Denmark [12], Romania [13], and Ireland [14]. All these studies have in common the focus on the energy sustainability and the utilization of renewables.

More specifically, a simulation model for Hong Kong's energy system is developed in [10], in order to examine the present energy structure and analyze alternative future sustainable energy strategies.

A strong emphasis on renewables is given in Refs. [11,12], where the performance of the Hungarian energy system with a higher share of renewables is analyzed in Ref. [11] and a 100% renewable energy system is designed for Denmark in 2050 in Ref. [12]. Similarly, the effect of an increase of intermittent renewable generation and reduction of nuclear power is investigated in Ref. [13] for the Romanian electricity system, whereas in Ref. [14] the optimal share of wind energy is determined for the Irish energy system in order to minimize the systems costs.

In the analysis of the energy system of a country, the electricity sector assumes a fundamental importance, because it represents one of the most energy intensive segment. Within European Union, Italy, with a consumption of ~316 TWh in 2013 [15], represents the fourth largest electricity market, after Germany (~531 TWh), France (~495 TWh) and United Kingdom (~326 TWh) [15].

Different studies are available on the Italian power market [15–20], but most of them are focused on the forecasting of future prices and energy related aspects are not deepened.

In fact, Vespucci et al. [16] proposed a model to reproduce the market clearing process and their model is particularly suitable for analyzing the behavior of market prices in electricity markets where a large dimensional producer can exert market power. Similarly, Gianfreda and Grossi [17] investigated the Italian electricity spot market with emphasis on price dynamics accounting for technologies, market concentration, congestions and volumes by utilizing a statistical/econometric approach.

Very recently Guerci and Fontini [18] analyzed the impact of the introduction of nuclear power in the Italian power system. The focus was the evaluation of its impact on the electricity price formed in the power-exchange market. Once again, the main focus is on power price and no emphasis is placed on the energy generated and on the primary resources needed.

According to the previous literature review [15–18], there is a lack of synthesis and integration between the economic drivers of the electricity market and the related energy and technological aspects. These two different features of the study of electricity generation sector have the same level of importance and they tend to influence each other, therefore it is authors' opinion that they should be considered at the same time.

To the best of authors' knowledge only two papers [19,20] are available in the open literature addressing the simulation of the Italian power sector from the energetic point of view.

The two studies investigate about the effect of renewables development in the Italian electricity system by utilizing Energy Plan [9]. They suggest different scenarios on the development of renewables and cogeneration plants, highlighting various possibilities for energy saving.

However, the representation they give of the power sector is quite approximate, because prices are not computed and fossil fuel power plants are not individually modeled. They are merged into a unique "large" plant which, in average, represents them. Therefore, an approximate representation of both the market and energy issues is given. In fact, in this way, it is not possible to simulate fuel switching phenomena due to the variation of fuel or carbon prices and fuels competition is not taken into account.

Even though a strong development of renewable energy in the electricity sector is detected in Italy and EU in the last years, most of the consumption is still satisfied by means of fossil fuels, in