Towards a Zero Emission Electricity Sector: A Pan-European Structural Electricity Integrated Model to assess Italian Power Generation and Transmission Expansion Pathways

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Overview

The pricing trend of gas, affecting the system marginal price and decrying the convenience of RES in the system, has a significant impact on the European electricity market and specifically on the Italian one. The price of gas listed on the European stock exchange has experienced a rapid growth since summer 2021 due to the conflict between Russia and Ukraine. The resulting surge in the wholesale electricity price has caused a three-fold increase in the typical domestic consumer's electricity bill. The combined action of global energy crisis, geopolitical tensions arising from Europe's dependence on gas and the increasingly pressing need to reduce global CO2 emissions (IPCC, 2022) brought to the revision of the European power system's emissions targets and generation pathway.

In line with Fit-for-55 package targets, Italy aims to increase the proportion of energy produced from Renewable Energy Sources (RES) to cover at least 65% of final consumption in the electricity sector by 2030, even over the previously planned 55% by Piano Nazionale Energia e Clima (PNIEC, 2021). On top of this, to accelerate the independence from Russian gas, REPowerEU calls for a 20% increase in the speed of renewable development compared to Fit for 55. In line with the most recent measures at European level, a revision of the PNIEC (first draft June 2023) is expected to update the national targets and to propose a new roadmap.

Achieving the above-mentioned European climate objectives implies a transformation of the electricity market that involves the coordinated and synergistic development of infrastructures, chemical or physical storage, renewable production, market coupling and market design. Which of the required interventions and to what extent these must be implemented requires a deep understanding of the gaps to be filled in order to achieve the stated goals.

This study contributes to the existing literature by proposing a pan-European structural electricity integrated model covering the latest infrastructure and economic figures presented in the TYNDP 2022.

Methods

The model used in this work is based on Plexos, a state-of-the-art power system simulator that can simulate electric markets with nodal and single substation granularity, ranging from long-term investment planning to short-term hourly and intra-hourly market simulations. It considers and evaluates power system security and adequacy metrics, calculates GHG emissions and sets target and custom constraints to conducts medium and long-term generation expansion optimisations and short term dispatching.

In order to achieve the objectives of this study, a comprehensive pan-European model was developed to simulate the functioning of EUPHEMIA (Pan-European Hybrid Electricity Market Integration Algorithm) used for market clearing across Europe. The tool is a structural model constructed using the TYNDP 2022 database and has a time horizon of 28 years, extending up to 2050. The model was designed to minimize the system costs' , optimizing italian generation expansions, while considering various degrees of sensitivities, constraints or objective functions. Among the many parameters subject to sensitivities there are:

- Mixes of technologies (including 4G Nuclear and Hydrogen);
- System designs; centralised or decentralised prosumer based system design;
- Climate objectives and constraints;
- Climate years affecting VRES production and competitiveness;
- Market competition mechanisms;
- Security and adequacy margins/parameters;
- Electricity load; high, medium, low electrification of final consumption;
- Hydrogen sector coupling.

The primary objective of the model is being a useful instrument for policy makers and other stakeholders. It allows to verify different expantion paths of the italian electric generation and transmission infrastructure. This validation process aims to attain an optimal economic, social, and technologically neutral outcome in both the short and long term, while adhering to the climate requirements mandated by the European community.

Results

The goodness-of-fit of the model is tested on the results of TYNDP 2022 as a benchmark, in addition a zonal detail is modelled. These results show that the calibration of the model for target years 2030, 40 and 50 is consistent, reproducing the same systemic and market functioning as the one described in the Global Ambition scenario of TYNDP 2022. From this important result, a fully unconstrained generation expansion simulation is carried out, i.e., without structural

constraints other than those related to climate targets and security and adequacy margins. For the "Unconstrained Optimization Scenario" preliminary results display that:

- By 2030 it is technically feasible and economically advantageous to run a completely carbon neutral Italian electricity system.
- The best optimization pathway, if let free, would choose distributed generation (prosumer engagement) as the most cost-effective solution to achieve climate neutrality goals.
- Technological neutrality would lead some investments toward the direction of 4th generation nuclear (Small Modular Reactor).

	INSTALLED CAPACITY [GW]			GENERATION [GWh]			
Category	**2030**	**2040**	**2050**	**Category**	**2030**	**2040**	**2050**
Thermal	42.5	23.7	22.1	**Thermal**	86,087	123,480	88,163
Nuclear (Of wich)	*-*	*10.2*	*12.9*				
VREs	250.7	256.3	284.9	**VREs**	344,221	362,914	429,745
Rooftop PV (Of wich)	*130.2*	*119.9*	*156.9*				
Total	**293.2**	**280.0**	**307.0**	**Total**	**430,308**	**486,394**	**517,909**

As per above table (table 1), VRES contribute to an average 80% of the total generation in Italy across target years. Concurrently, the remainder 20% is covered by synchronous renewable thermal generation (hydrogen, biomethane, nuclear and natural gas with CCS) ensuring system security and adequacy margins (table 2).

	ADEQUACY METRICS		PRICES	EMISSIONS
	LOLE (day)	***LOLP (%)***	***Region price [€/MWh]***	***Production (tonne)***
2030	-	-	46.76	-
2040	-	-	31.76	-
2050	-	-	63.71	-

Conclusion

Electricity demand in Italy has been stable for around a decade but it will inevitably rise in the long term as the government promotes electrification in transport, heating and industry. As a consequence, Italy will need to install significant amounts of additional variable renewables capacity in order to comply with the EU's Fit-for-55 package and meet its own long-term decarbonisation goals. The addition of large amounts of variable renewables capacity will necessitate significant planning and investment, as well as balancing and storage capacities. Considering the important role played by prosumers, for the policy makers it's important to understand the energy exchange between the end-users and the power grid, as well as the rules for their connection to the grid, the implementation of Demand Response and other energy management programs. This paper highlights the issues that must still be addressed for a complete implementation of the new power system.

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