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The role of Energy Storage and Conversion Systems in Ecological Transition

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Research context and motivation

- Main **aim** of the **Green Deal** is to reach **climate neutrality** in **Europe** no later than **2050**, with intermediate commitment of reducing GHG emissions towards 55%[1] in 2030
- Particularly, ¾ of **GHG emissions** in **Europe** come from the **energy sector**[2], therefore representing the crucial sector in order to reach the EU's climate neutrality
- Decarbonize the energy generation side requires a **shift** from **fossil fuel-based** power plants (especially coal) to **renewable** ones, especially photovoltaic and wind
- The consequent **rise** on **renewable** capacity and generation needed to reach EU's decarbonisation targets can represent an **issue** for power **grids** → Both **photovoltaic** and **wind** power **plants** depends on **meteorological** factors, causing a great oscillation on generation within the day and the seasons
- Daily **variability** determines **renewable overgeneration**[3] issues during some **hours** of the **day** and **undergeneration**[3] (or lack of generation) in **others**[4]; seasonal variability instead is caused by unbalance on seasonal generation
- Additionally, they are characterised by **high intermittency** →can lead to **frequency** value **deviation** from the **nominal** value
- Needs for **flexibility options** in order to guarantee the proper working of electrical grids → **Energy Storage** and **Conversion Systems**, **Demand-Side Management**, **Demand Response**

[1]Compared to 1990 EU's emissions
[2]Considering both production and use of energy
[3]Compared to power demand
[4]Especially for photovoltaic the excess on generation appears on midday and the drop in production during the evenings

Addressed research questions/problems

- In this framework, **Energy Storage** and **Conversion Technologies** (**ESCTs**) could be exploited in order to **provide** useful **services** and **applications** to the **electro-energetic system**, such as:
  - **Storage** of **energy** during period of renewable **overgeneration**
  - **Release**[1] during **positive residual load**
  - As support tools for **frequency** and **voltage regulation**
- Energy Conversion Technologies, such as **Power-to-Gas** (**PtG**), are **suitable** both for **frequency regulation** and for **congestion relief**
- Moreover, **PtG produce** a valuable energy vector (i.e., H_2) whose **demand** is **growing**
- **PtG** has to be evaluated from a technical point of view, considering the **potential** both in terms of **congestion management** as well as for satisfying **future H_2 demand**

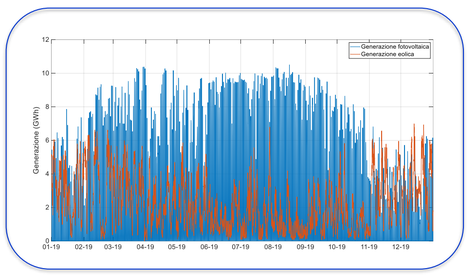
Within this context, the **PhD work focused** on:
- **Identifying** the **PtG potential** for **congestion relief** in the national **transmission grid**
- **Identifying** the **PtG potential** for **covering** the **future demand** of **hydrogen**

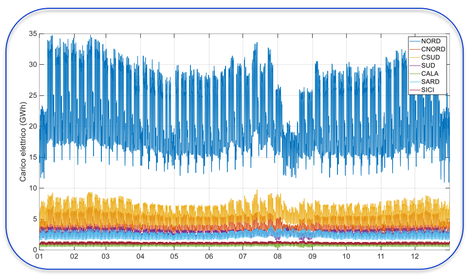
Novel contributions

- **Proposal** of **congestion management strategies** for dealing with future VRES overgeneration, **based** on the **exploitation** of **PtG**
- **Identification** of **production** and satisfied **demand** of **hydrogen** based on **future projections** and the **exploitation** of an **optimisation model**
- Evaluation of **best management strategies** for **PtG** in order to **reduce VRES curtailment** and **increase** the **demand coverage** at **2040**

Adopted methodologies

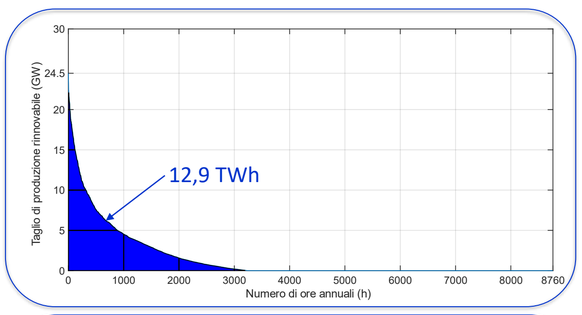
- **Optimization** model whose objective function is to **minimise** the **total operational costs** of the **grid**
- **Three** different **scenarios** are **considered**, differing on demand, VRES and electrical storage installed capacity →**National Trends** (NT), **Distributed Energy** (DE) and **Global Ambition** (GA)
- For each scenario **three cases** of **PtG penetration** are investigated :
  - **Complete coverage** of **VRES curtailment** through the exploitation of PtG plant in generation-following mode (**Case 1**)
  - **Full-load mode** of PtG plants (**Case 2**)
  - **Generation-following mode** with power **size** of PtG **lower** than the **peak** power

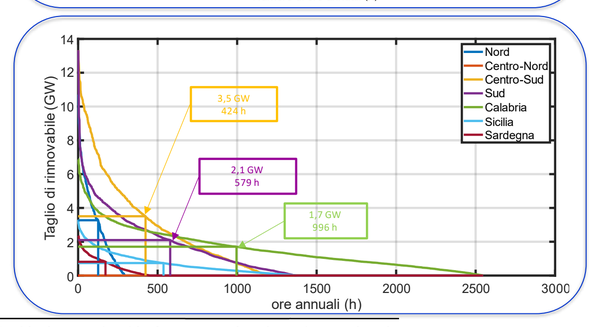




Results

- Exploitation of **PtG** plants allows to **absorb** VRES **overgeneration** that otherwise would be curtailed
- **Global Ambition** scenario **allows**, in all the cases considered, a **higher H_2 production** and **demand coverage** compared to the other scenarios
- In the full-load mode (**Case 2**) of **Global Ambition** scenario, **PtG** is able to **cover** approximately **one-half** of forecasted **demand of H_2 at 2040**





Scenario	VRES Curtailment (TWh)	Case	PtG Installed (GW)	Residual curtailment (TWh)	% residual curtailment	H_2 produced (kt/year)	% H_2 produced wrt demand 2040
National Trend (NT)	10.9	Case 1	22.1	0	0	246.8	9
		Case 2	4.1	3.6	33	804.8	29.4
		Case 3	4.1	5.2	47.7	128.7	4.7
Distributed Energy (DE)	6.1	Case 1	17.7	0	0	136.9	5
		Case 2	4.3	2.5	41	735	26.9
		Case 3	4.3	2.7	44.3	75.7	2.8
Global Ambition (GA)	12.9	Case 1	24.5	0	0	291.7	10.7
		Case 2	7.3	3.8	29.5	1442.6	52.8
		Case 3	7.3	5.3	41.1	171.3	6.3

Future work

- **Analysis** of further **Power-to-X pathways**, such as Power-to-Methane (PtM) and Power-to-Fuels (PtF)
- Addressing **other issues** related to **ecological transition**, **apart** from the **economic** and **technical** considered
- **Environmental** and **social aspects** have to be faced →**holistic approach** for the **evaluation** of **Energy Storage** and **Conversion Technologies**

Submitted and published works

- Ilaria Abbà, Salvatore Cellura, Stefano Paolo Corgnati, Silvia Morassutti, Leonardo Prendin Overall Energy Performance of polyvalent Heat Pump systems, REHVA Journal (2020)
- Ettore Bompard, Carmelo Mosca, Salvatore Cellura, Stefano Corgnati, L'impatto del COVID-19 sul carico elettrico nazionale/2, rivista ENERGIA (2020)
- Ettore Bompard, Salvatore Cellura, Alessandro Ciocia, Filippo Spertino, Gianluca Fulli, Marcelo Masera, Arturs Purvins, Silvia Vitiello Impact of RES electricity exchanges between North Africa and the EU power systems and markets, MED & Italian Energy Report / S.N., S.L., Giannini Editore, pp. 147-167. ISBN: 978-88-6906-121-9 (2020)
- G. Tumminia, F. Guarino, S. Longo, D.Aloisio, S.Cellura, F.Sergi, G.Brunaccini, V.Antonucci, M.Ferraro Grid interaction and environmental impact of a net zero energy building, Energy Conversion and Management 203:112228 (2020)
- G. Tumminia, F. Guarino, S. Longo, D.Aloisio, S.Cellura, F.Sergi, G.Brunaccini, V.Antonucci, M.Ferraro Analysis of the effects of climate change on the energy and environmental performance of a building with and without onsite generation from renewable energy , Smart Innovation, Systems and Technologies, 178 SIST, pp. 1380–1391 (2021)
- Ettore Bompard, Salvatore Cellura, Domenico Ferrero, Marta Gandiglio, Daniele Grosso, Stefano Lo Russo, Paolo Marocco, Andrea Mazza, Massimo Santarelli Technologies, Emerging Industrial Chains and Critical Materials for Hydrogen in the Mediterranean, MED & Italian Energy Report / S.N., S.L., Giannini Editore, pp. 83-116. ISBN: 978-88-6906-201-8 (2021)
- G. Tumminia, F.Sergi, D. Aloisio, S. Longo, M. A. Cusenza, F. Guarino, S. Cellura, M.Ferraro Towards an integrated design of renewable electricity generation and storage systems for NZEB use: A parametric analysis, Journal of Building Engineering 44: 103288 (2021)

List of attended classes

- 01LGSRV – Characterization and planning of small-scale multigeneration systems (17/9/2021, 41.67)
- 02LWHRV – Communication (21/12/2019, 6.67)
- 01LYXRV – Electrical load management, forecasting and control (25/09/2020, 33.33)
- 01QUGIV – Energy in smart buildings (02/07/2021, 13.33)
- 01UJERV – Energy sustainability and security (01/09/2021, 21.33)
- 01SHMRV – Entrepreneurial Finance (08/04/2022, 6.67)
- 02ITTRV – Generatori e impianti fotovoltaici (14/04/2021, 33.33)
- 01LXBRW – Life Cycle Assessment (LCA) (08/06/2020, 41.67)
- 02RGKRS – Multicriteria analysis and strategic assessment (05/07/2021, 25)
- 01UNVRV – Navigating the hiring process: CV, tests, interview (08/04/2022, 2.67)
- 01UNYRV – Personal branding (05/04/2022, 1.33)
- 01LEVRV – Power system economics (20/05/2020, 20)
- 02SFURV – Programmazione scientifica avanzata in matlab (26/05/2022, 40)
- 08IXTRV – Project management (07/04/2022, 6.67)
- 01RISRV – Public speaking (20/12/2019, 6.67)
- 01SYBRV – Research integrity (07/04/2022, 6.67)
- 01SWQRV – Responsible research and innovation, the impact on social challenges (21/12/2019, 6.67)
- 02RHORV – The new Internet Society: entering the black-box of digital innovations (08/04/2022, 8)
- 01UNXRV –Thinking out of the box (05/04/2022, 1.33)
- 01SWPRV –Time management (06/12/2019, 2.67)

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