Multi-agent reinforcement Learning for modeling electricity markets during the Energy Transition

Javier Gonzalez-Ruiz [a,b,c]

Supervisor – Professor Massimo Tavoni [a,b,c]

[a] *CMCC Foundation - Euro-Mediterranean Center on Climate Change, Italy.*
[b] *RFF-CMCC European Institute on Economics and the Environment, Italy.*
[c] *Politecnico di Milano, Italy.*

27/03/24

CMCC Centro Euro-Mediterraneo sui Cambiamenti Climatici

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Electricity Market Design and Modeling Decarbonization

For a fast and efficient decarbonization during the transition, properly functioning electricity markets are crucial

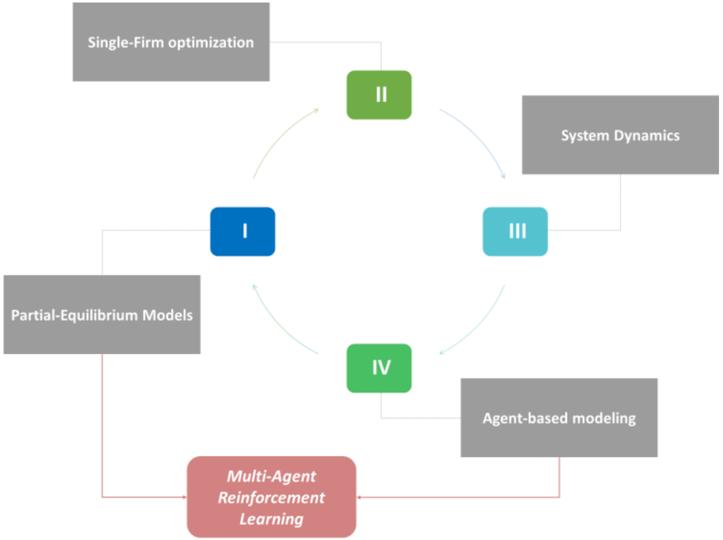
Existing Paradigms

- Energy-only-Markets [1]
- Capacity Remuneration Mechanisms [2]

Reforms and Proposals

- Fixed-price Forward Contract Approach to Long-term Resource Adequacy [3]
- Affordability Options [4]
- Improved Contracts for Difference for RES Penetration [5-6]
- Hybrid Markets (*Competition for the Market and Competition in the Market)* [7-9]
- Eup. Comi. Voluntary Forward Contracts, CfDs and PPAs [10]
- ¿?

Considering existing tools for market assessment, Multi-Agent Reinforcement Learning could breach the gap between Agent-Based [11-13] and Partial-Equilibrium models [14-16]



Modeling overview for adequacy considerations. Inspired by the review presented in [17]

Multi-agent Reinforcement Learning (*MARL*) For Electricity Markets

Conventional Formulation for profit-maximizing agents

Profit maximization for GENCO i

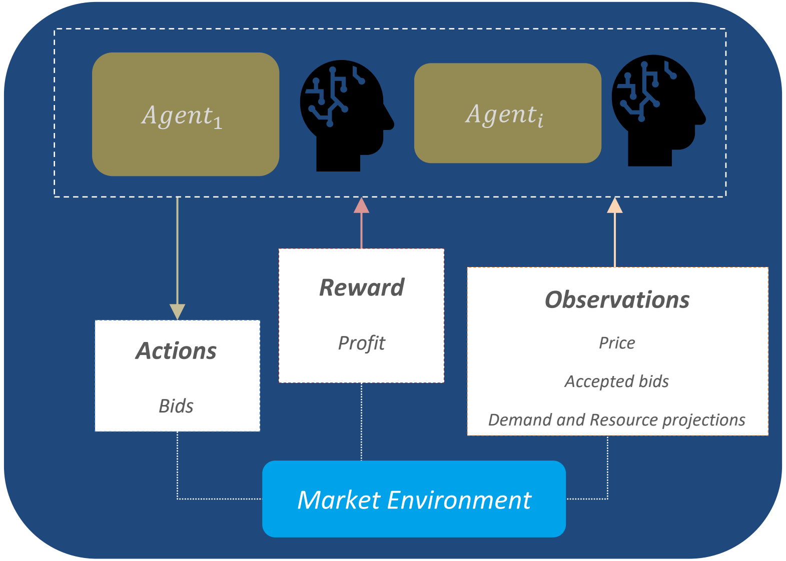
$$\max_{\pi^{g}_{i,p,t},\,\pi^{ch}_{i,b,t},\,\pi^{disch}_{i,b,t}} \sum_{t=1}^{T}\left\{\sum_{p=1}^{P} Q^{g}_{i,p,t}(\pi^{*}_{t} - VC_{i}) + \sum_{b=1}^{B}\left(Q^{dish}_{i,b,t} - Q^{ch}_{i,b,t}\right)\pi^{*}_{t}\right\}\gamma^{t}$$

$s.t.$

Economic and Technical constraints

$\pi^{g}_{i,p,t}, \pi^{ch}_{i,b,t}, \pi^{disch}_{i,b,t}$ → *Marginal Price Auction* → π^{*}_{t}

Independent Learning using Proximal Policy Optimization - PPO [19], while simultaneously interacting in a market environment

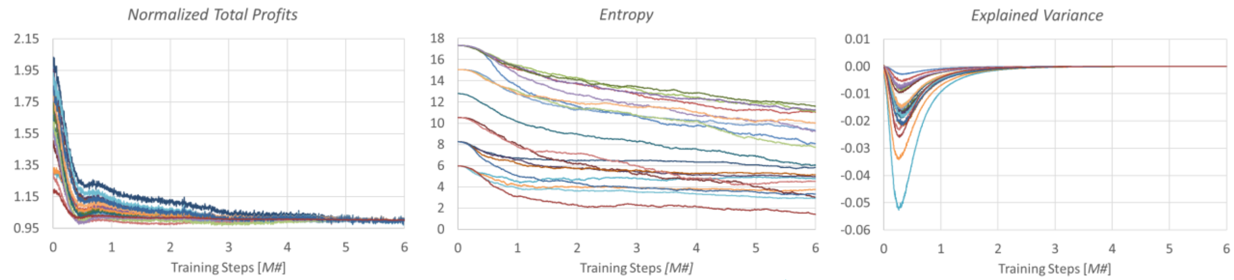


Implementation using RayLib, an open-source library, ideally suited for distributed computing and multi-agent implementations [18]

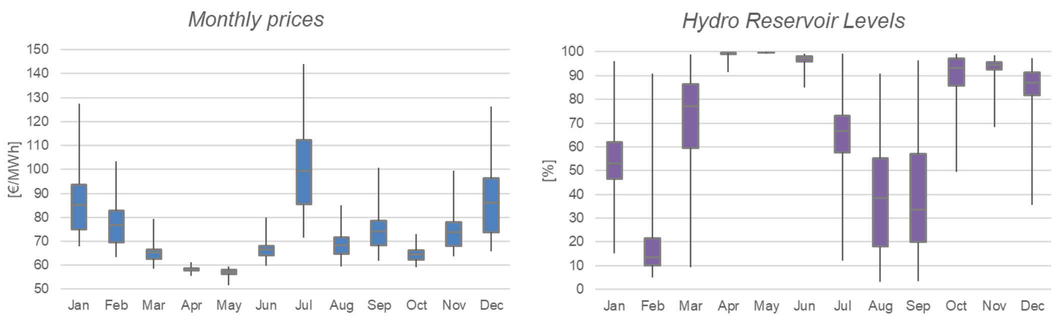
Some Results…

Test-bench Information – Based on [20]

- 2019 Italian Generation Mix and 6 main technologies (*Solar, Wind, Pumped Hydro, Coal, Combined Cycle, and Open Cycle)*
- 20 Agents with a Herfindahl-Hirschman Index - HHI (Installed Capacity) of 867 compared to 652 reported by ARERA [21]
- Historical demand and renewable resource availability in hourly resolution, with some added uncertainty
- Hourly auctions, but strategic bidding decisions by agents taken monthly
- PPO hyperparameters manually tuned following guidelines from [22-23]



Converging, but maybe to a local optimum?



Using trained agents, market outcomes across *1k* runs

Relevant issues and final comments

- How to deal with Model-free algorithms (*such as PPO)* lacking long-term planning capabilities?
- Are Market Equilibriums and Agent's Responses Robust?
- Scalability and parameter sharing in competitive environments?
- Is MARL improving over existing modeling approaches? Can it complement other models?

Thanks!

Contact Information
Javier Gonzalez-Ruiz
javier.gonzalez@cmcc.it

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