A multi-agent simulation model considering the bounded rationality of market participants: an example of GENCOs participation in the electricity spot market

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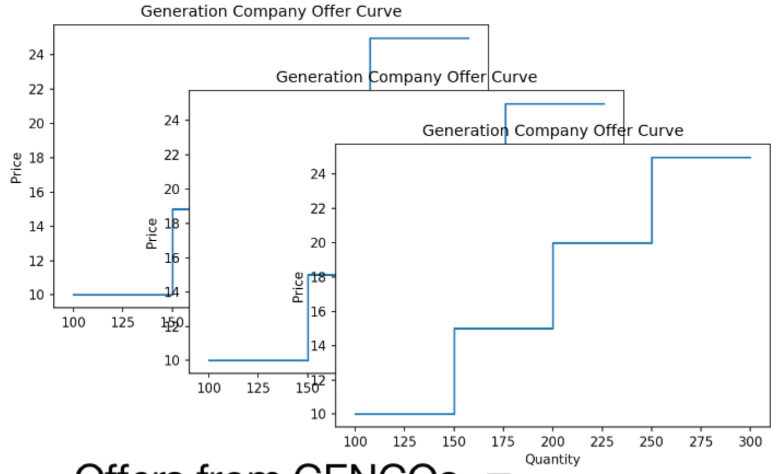
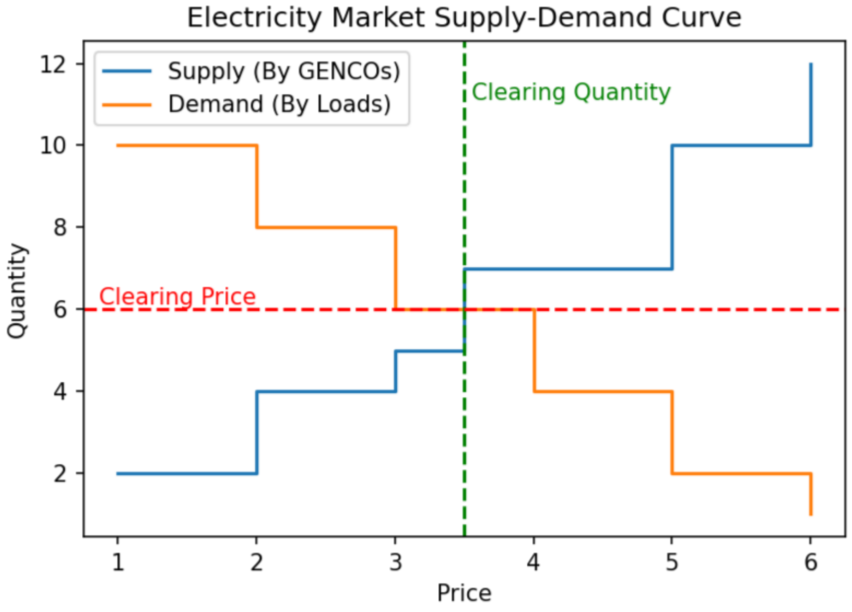
Electricity spot market (ESM)

GENCOs(Generation companies) declares a monotonically increasing curve as their willingness to offer electricity supply at different prices.

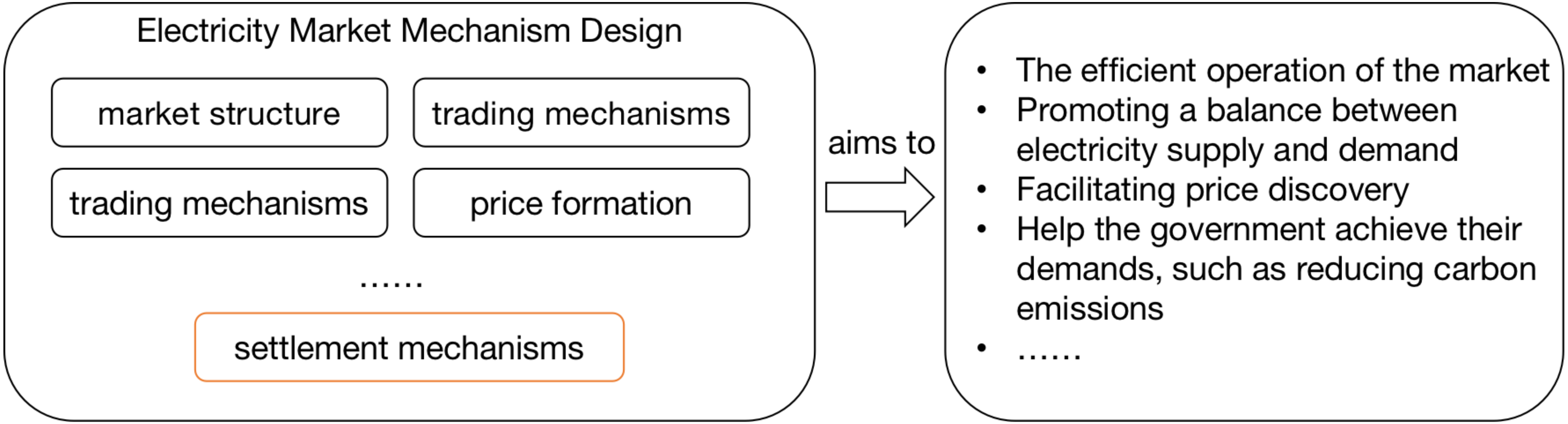


Offers from GENCOs

ISO (Independent System Operator) will clear the market based on the supply and demand curves submitted by Gencos and loads, resulting in the determination of electricity prices and quantities.



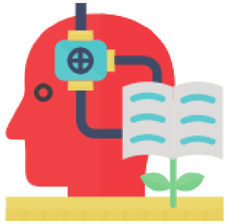
Electricity Market Mechanism Design



The design of electricity market mechanisms is a topic of interest. Today, my presentation focuses on the issue of settlement mechanisms.

Our approach can be applied to other aspects of mechanism design as well.

Bounded rationality (BR)



human
decision-making

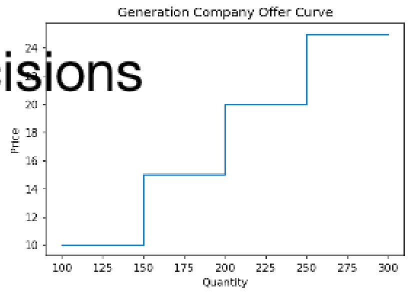
satisfice > optimize

Attempting to optimize their decisions
(but they cannot).

GENCOs

Load forecasting
Self generation costs
Offers from other GENCOs.
……

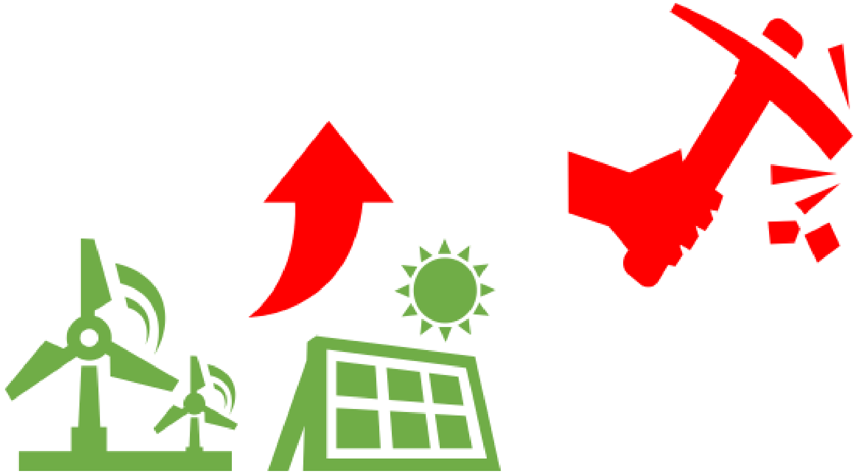
complex decisions

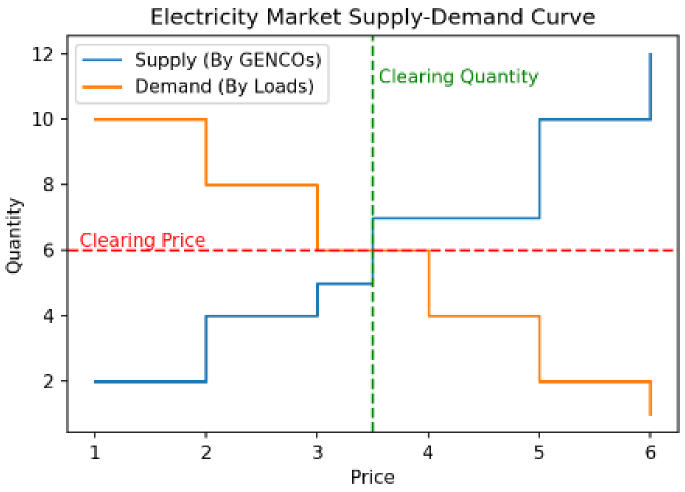


Limit Time (Every 5 minutes)
Limited market information

Why do we consider BR of GENCOs in the ESM?

With the increasing scale of renewable energy, the volatility of the electricity market has become more evident, leading to less accurate predictions by market participants regarding the future.





We aim to simulate the bounded rationality of GENCOs and observe the changes that occur in the electricity market under unstable conditions. This will enable us to design a better market mechanism.

Electricity Market Simulation Process

Every period:

① GENCO's decision model makes a decision.

② GENCO converts the model outputs into offers.

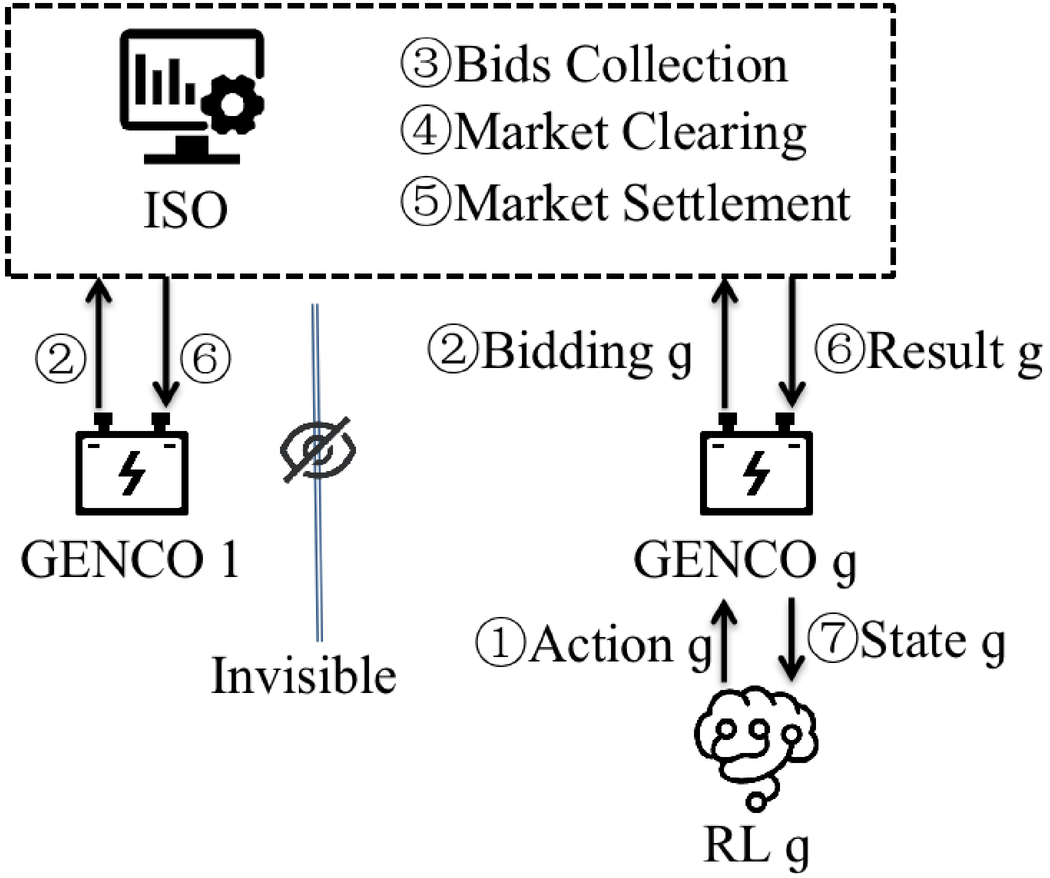
③ ISO collects all offers.

④ ISO performs market clearing.

⑤ ISO settlement to obtain the winning power and revenue of each GENCO

⑥ ISO sends the market results back.

⑦GENCO receives the market clearing results and prepares for the next iteration.



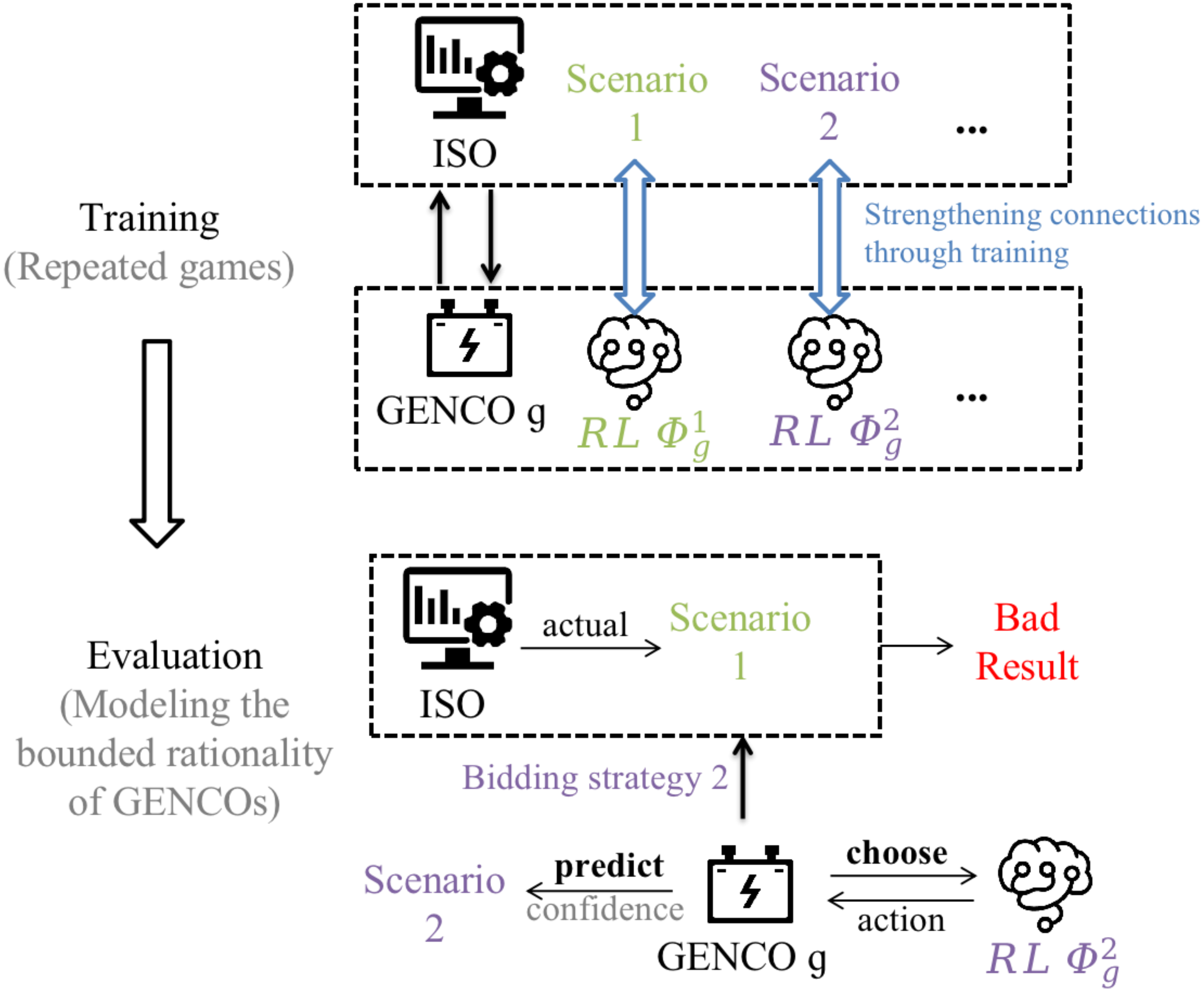
Simulation Model Considering the BR of GENCOs

Training phase :

1, ISO presets N_s typical scenarios with different market boundary information, and the m^{th} scenario :

$$S_m \in \{S1, S2 \ldots S_{Ns}\}$$

2, each scenario S_m is used for training purposes, where the parameters of S_m (market boundary conditions, such as load curves), are fixed, and the RL model Φ_g^m is trained for each GENCO g under each S_m .



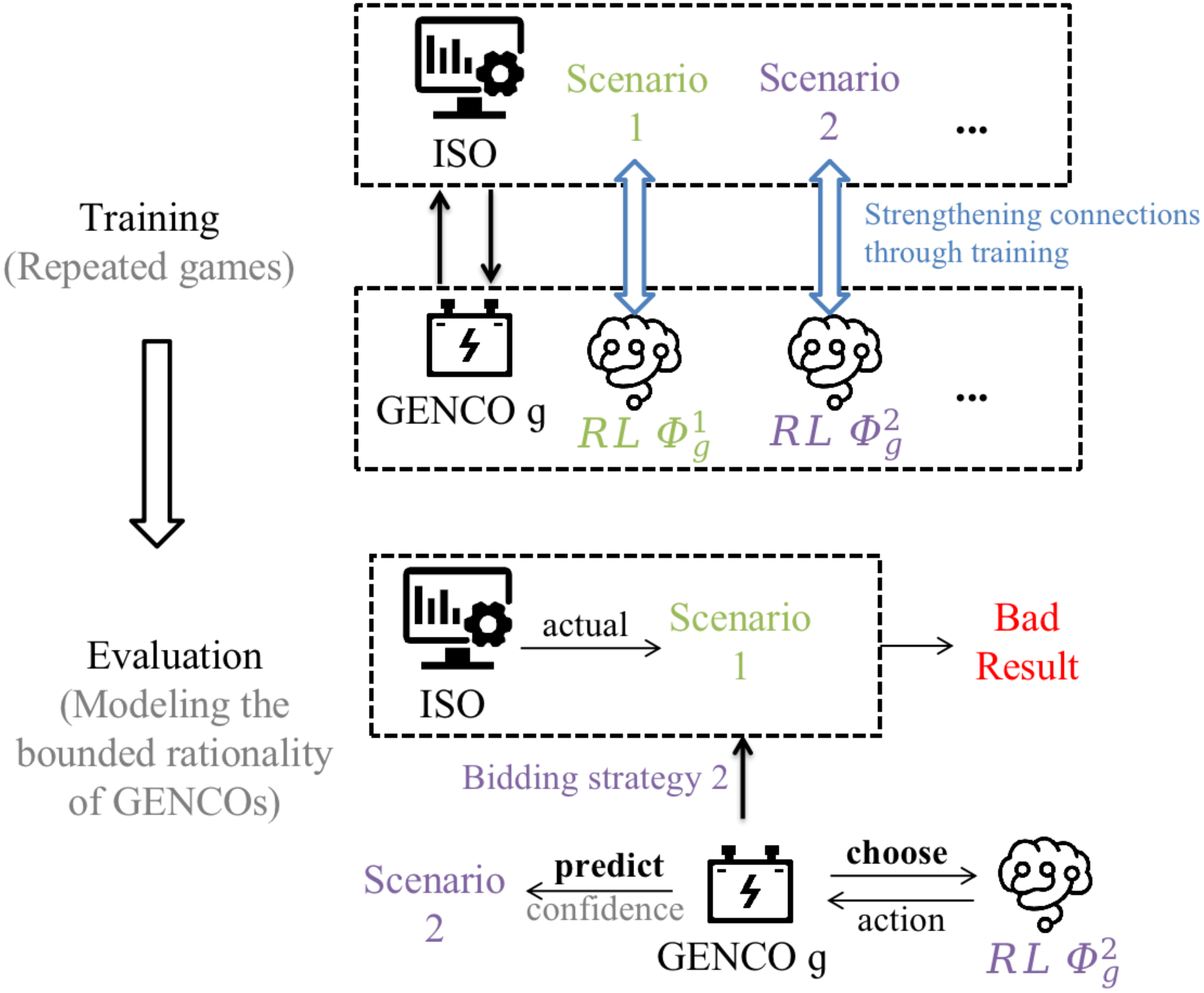
Simulation Model Considering the BR of GENCOs

Training phase :

3, The decision model for GENCO g is

$$\rho_g = \{\Phi_g^1, \Phi_g^2 \ldots \Phi_g^m\}$$

4, The above steps are repeated for each market rule θ in the set of rules to be studied , to obtain the decision model ρ_g^θ for GENCO g under different rules.



Simulation Model Considering the BR of GENCOs

Evaluation phase :

1, predict and action

pridict

GENCO g scenario S_m

⇩

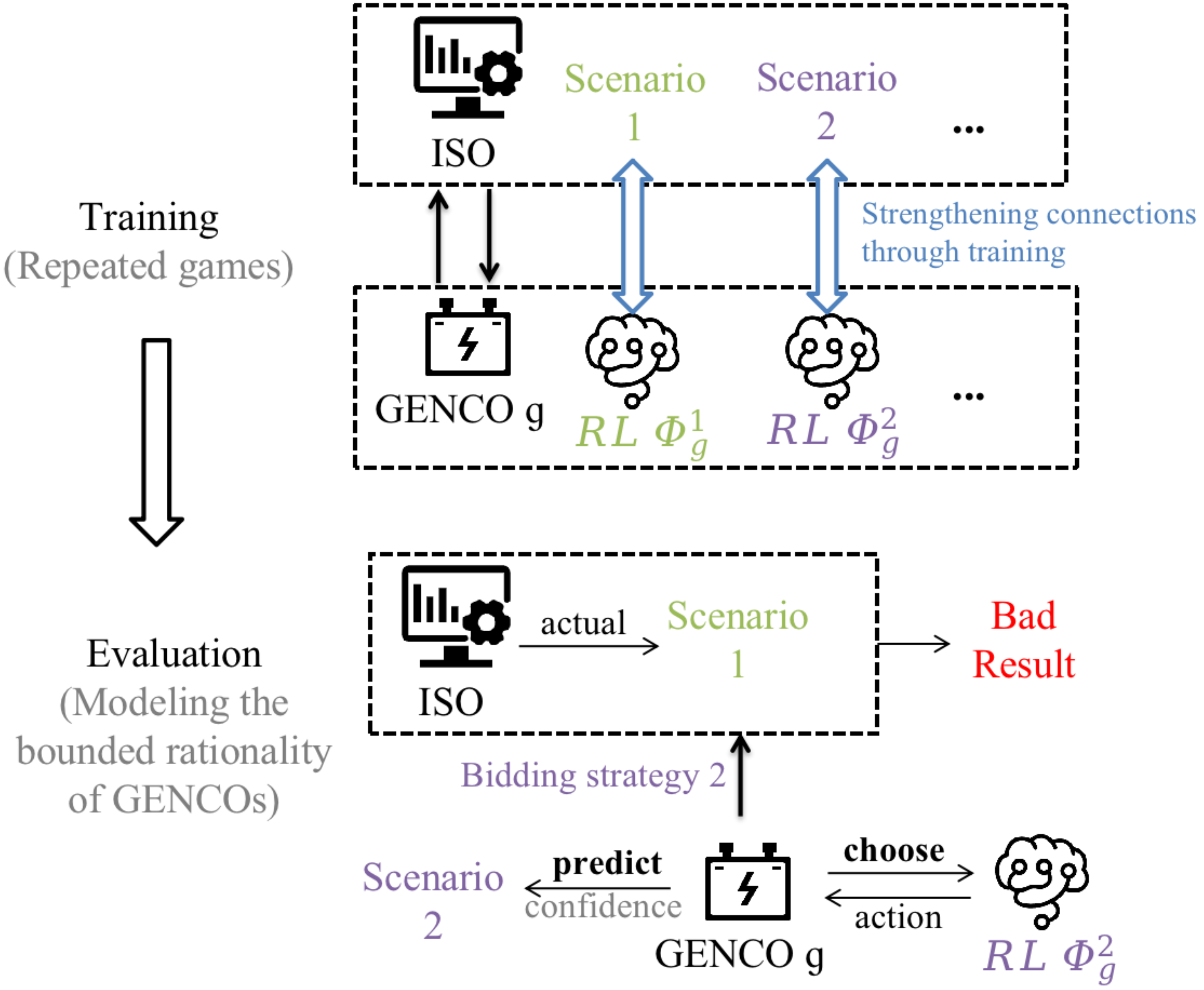
Action g ✓

Actual scenario S_m →

⇩

result R_m^{base}

market indicators I_m^{base}

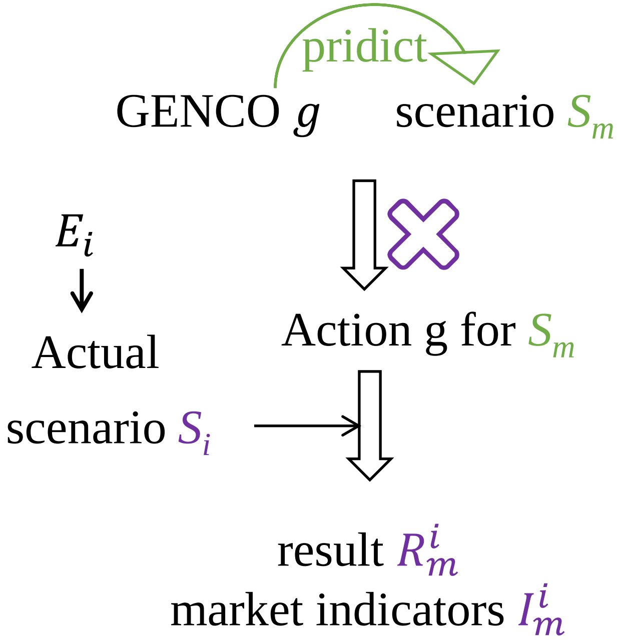


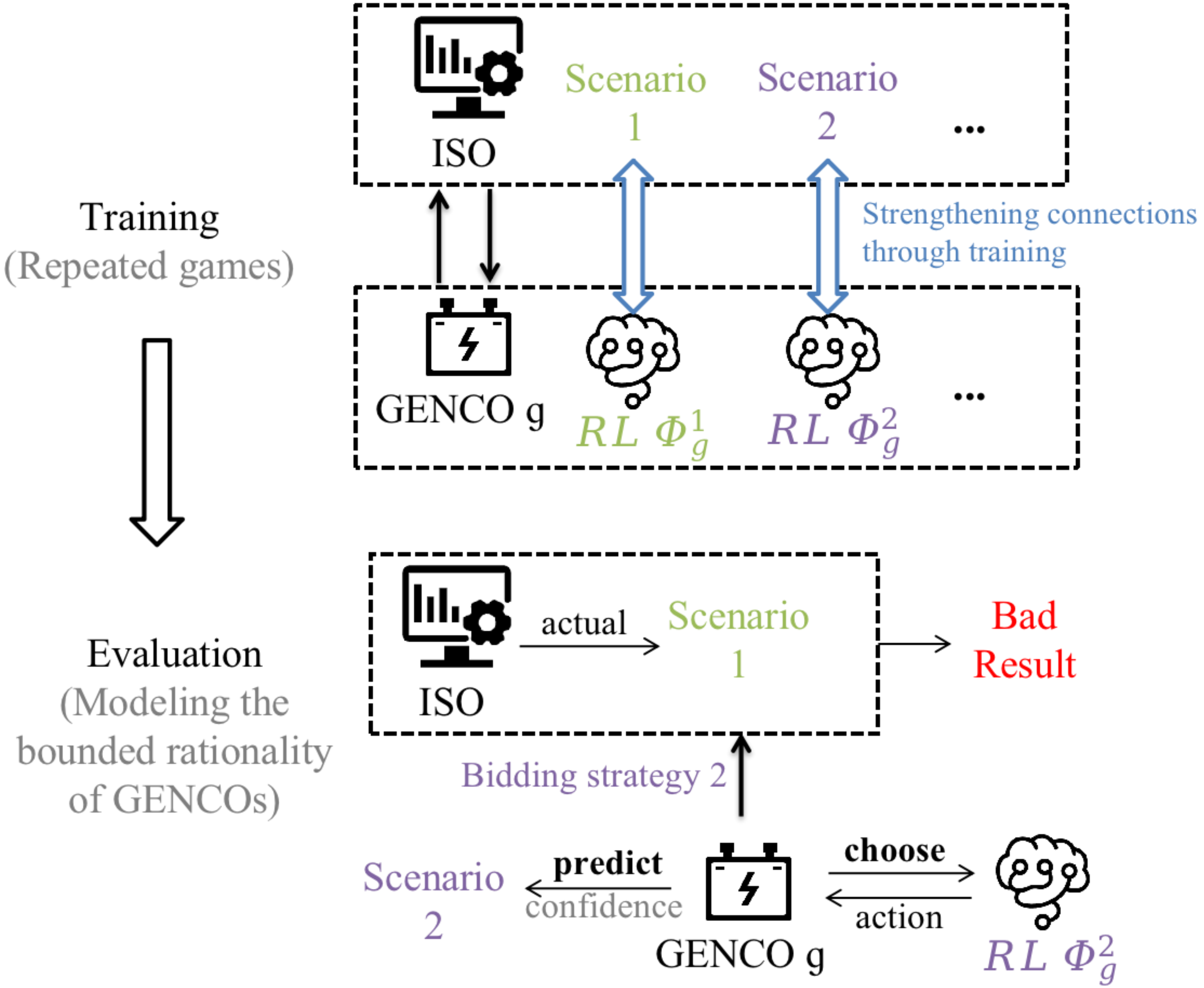
Simulation Model Considering the BR of GENCOs

Evaluation phase :

2, Contingency events E_i

GENCOs misjudging current scenario S_m





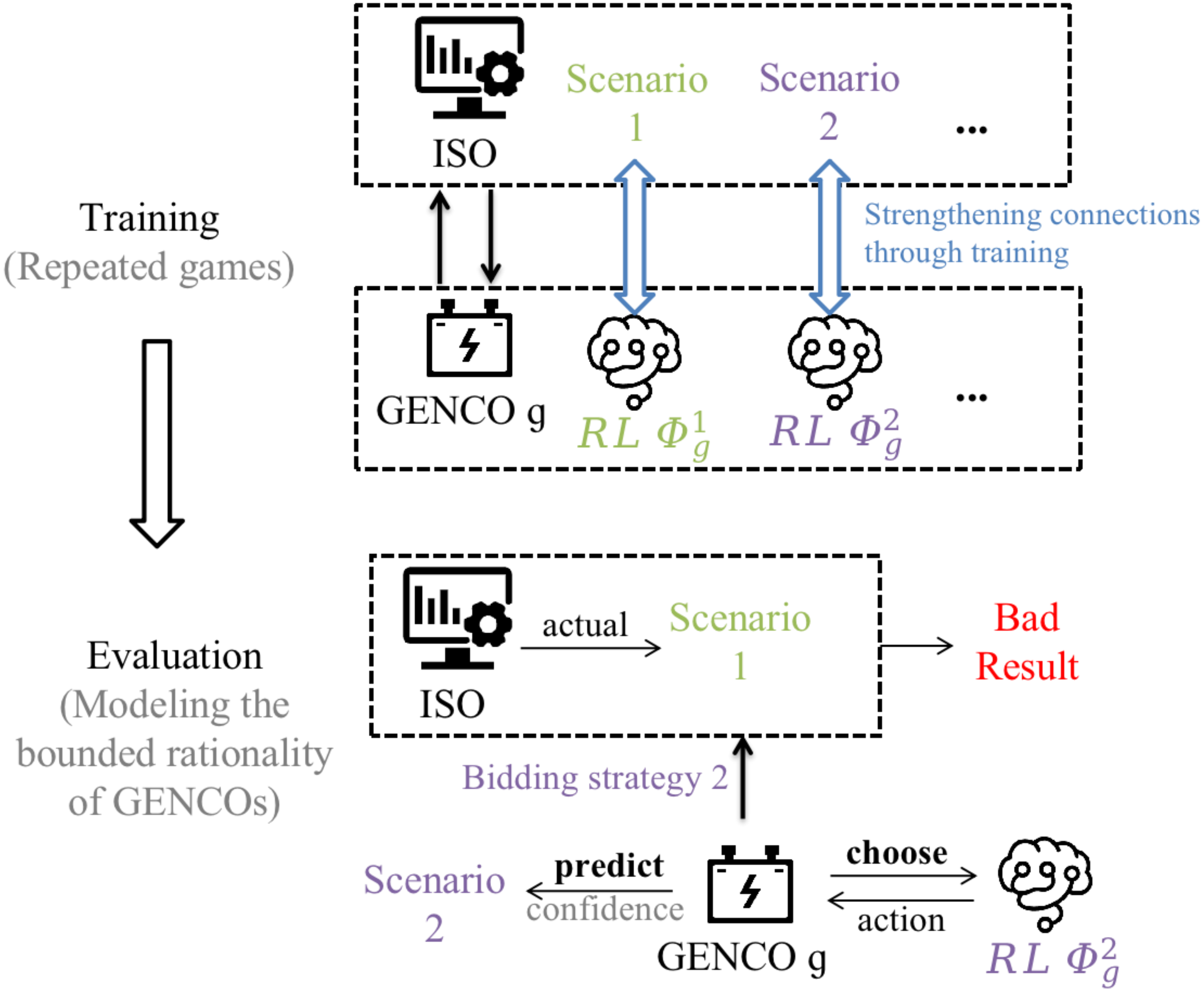
Simulation Model Considering the BR of GENCOs

Evaluation phase :

3, The maximum deviation is calculated for all contingencies and all scenarios for different market rules θ.

4, By assessing A_θ for different market rules, it is possible to determine the shock resistance of each rule, where the more shock-resistant the market rule, the smaller the A_θ.

$$A_m^i = \frac{\left|I_m^i - I_m^{base}\right|}{I_m^{base}} \times 100\%$$

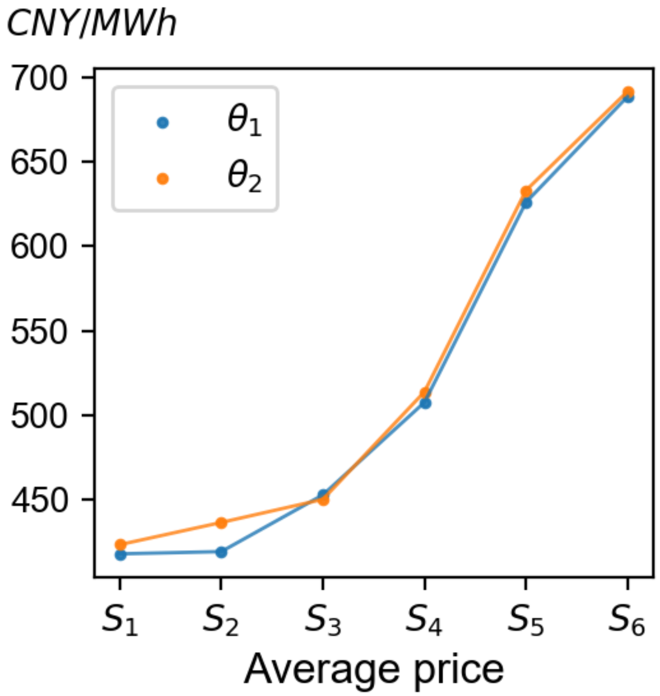


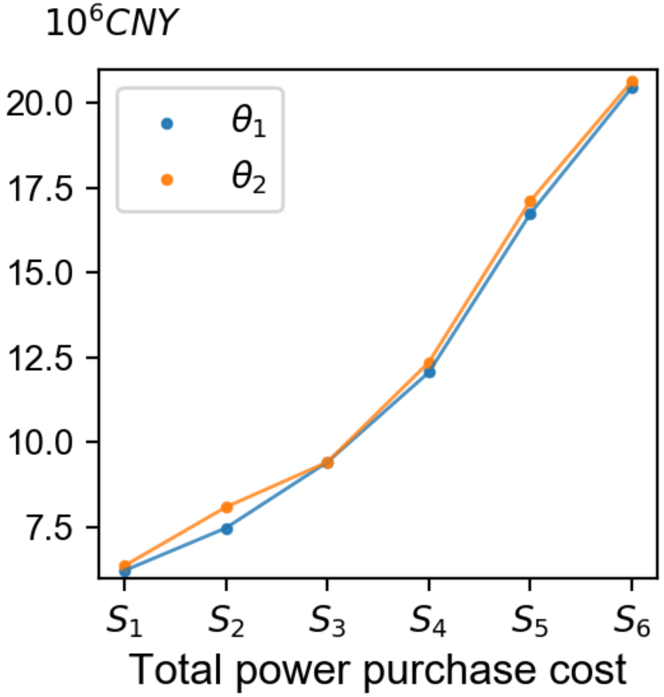
Set of Mechanisms to be Studied

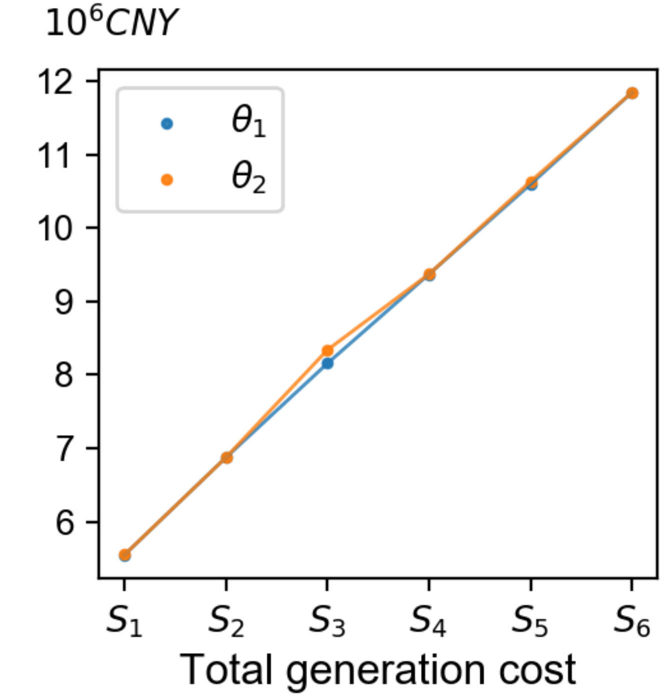
Symbols	Mechanism Name	Additional Notes
θ_1	Make-Whole Payment	Only the spot market is considered, consider full day losses, the loss is fully compensated.
θ_2	No compensation	No compensation payments to GENCOs
θ_3	Consider Long-term Contracts	ISO considers long-term contract revenue when approving GENCO's revenue.

This paper examines a set of market mechanism designs denoted as θ, which includes the make-whole payment (MWP) employed by PJM and the electricity market mechanisms adopted in several Chinese provinces.

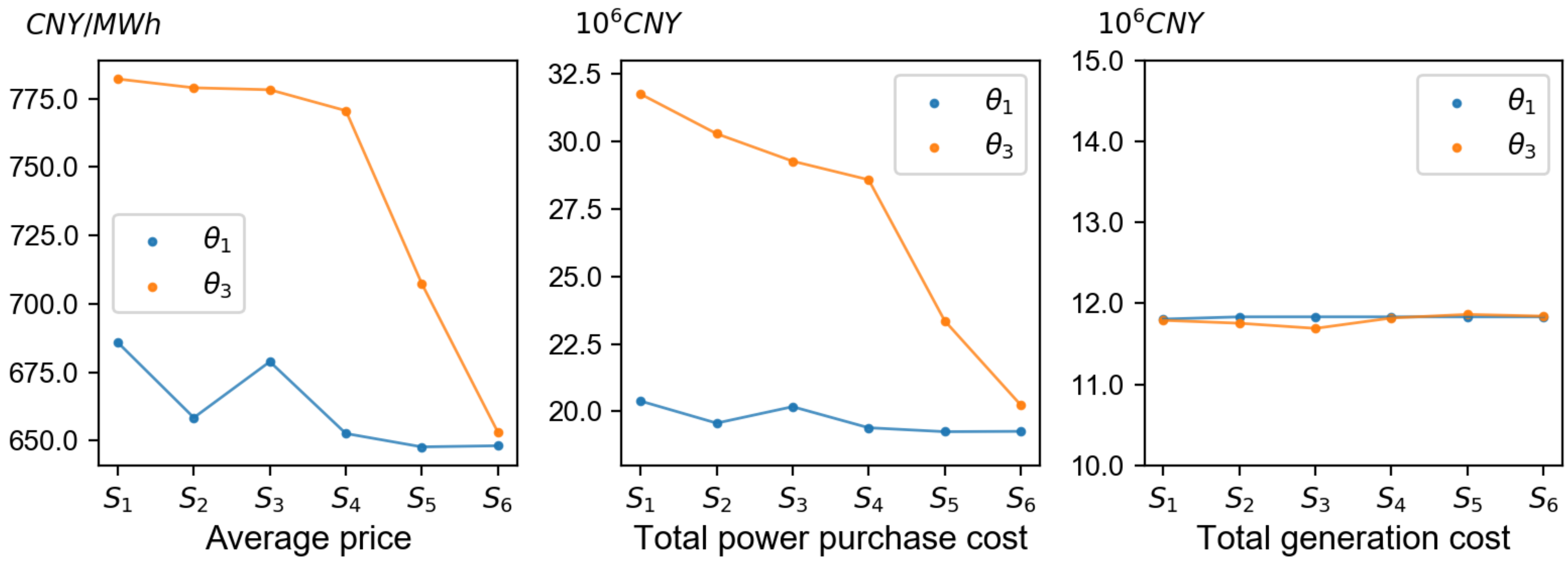
Comparison of θ_1 and θ_2



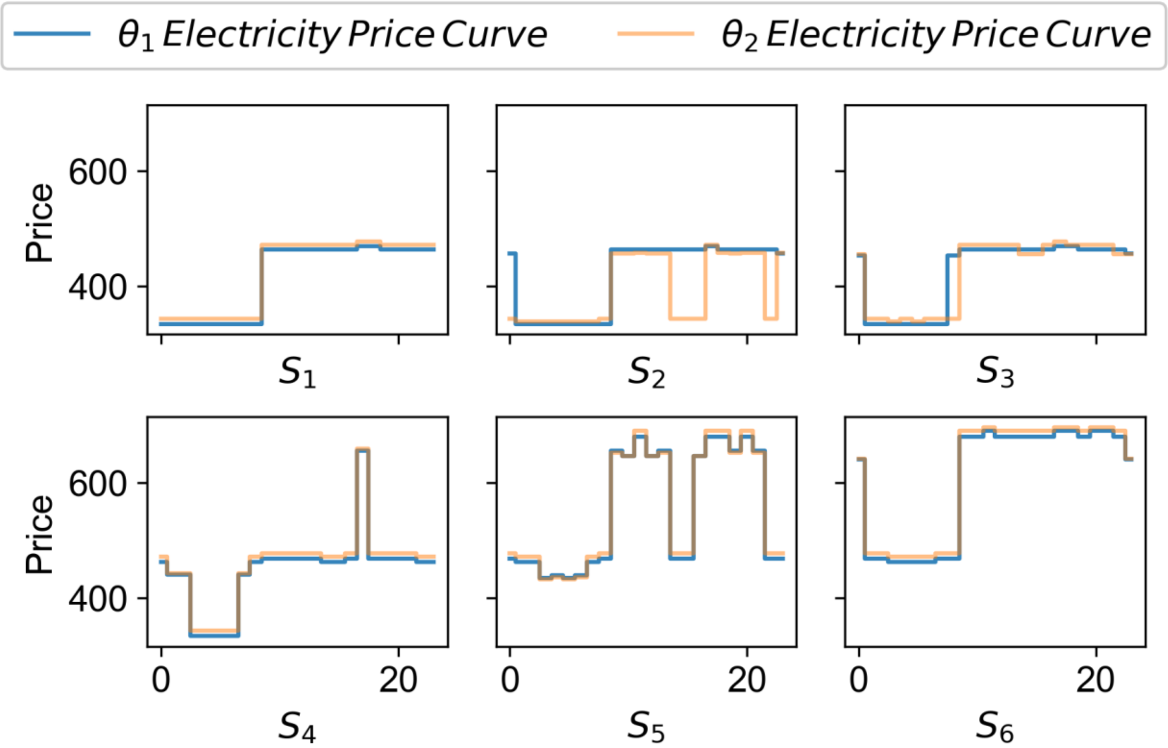




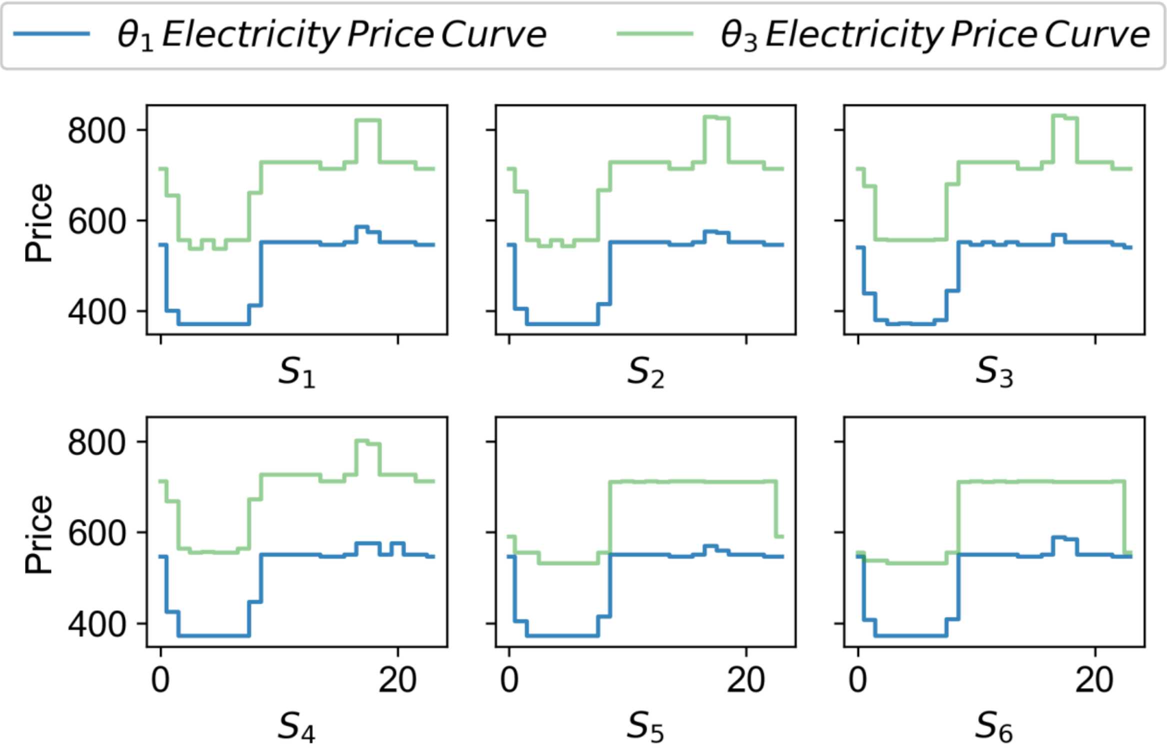
Comparison of θ_1 and θ_3



Simulation that Considering Bounded Rationality



Event E_1: θ_1 and θ_2



Event E_2: θ_1 and θ_3

We consider randomly selecting certain GENCOs to mispredict the current electricity market scenario. For example, the selected GENCOs might think that the current scenario is S_1 while the actual scenarios are $S_1 - S_6$.

Comparison of Market Indicators Considering BR

Comparison of the A_m^i under different mechanisms.

	E^1	S_1	S_2	S_3	S_4	S_5	S_6	E^2	S_1	S_2	S_3	S_4	S_5	S_6
$A^i_{m,price}$	θ_1	6.3	5.8	3.8	7.3	5.5	10.1	θ_1	1.2	1.2	1.0	1.2	1.2	1.2
	θ_2	12.3	1.4	4.1	5.9	4.6	9.0	θ_3	13.0	13.0	12.8	12.7	16.3	15.7
$A^i_{m,pc}$	θ_1	5.2	5.0	3.8	7.3	5.5	10.1	θ_1	1.2	1.2	1.0	1.1	1.2	1.2
	θ_2	12.3	1.4	4.1	5.9	4.6	9.0	θ_3	17.2	17.9	18.5	19.1	24.1	24.4
$A^i_{m,gc}$	θ_1	3.4	2.4	0.8	0.0	0.0	0.0	θ_1	0.2	0.2	0.1	0.1	0.2	0.2
	θ_2	3.5	0.0	0.0	0.0	0.0	0.0	θ_3	1.2	0.7	0.5	1.2	0.9	0.8

Comparison of the A_θ under different mechanisms.

	$A_{\theta,price}$	$A_{\theta,pc}$	$A_{\theta,gc}$		$A_{\theta,price}$	$A_{\theta,pc}$	$A_{\theta,gc}$
θ_1	10.1	10.1	3.4	θ_1	1.2	1.2	0.2
θ_2	12.3	12.3	3.5	θ_3	16.3	24.4	1.2

Conclusion

This study proposes a multi-agent simulation model that considers the bounded rationality of GENCOs and presents indicators to evaluate the shock resistance of the electricity market.

The multi-agent simulation model proposed in this paper can be extended to other economic systems. The model employs multiple RL algorithms to form a decision model for each market participant, which can adapt to different simulation scenarios and thereby reduces the generalization requirements of RL algorithms.

Thank you!