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Cross-sectoral synergy policy in climate-neutral sustainable cities with eco-friendly public transportation fleets and hydrogen-pivoted multi-energy transactions

Amir Mohammadian [a,b], Abdolmajid Dejamkhooy [a,*], SeyedJalal SeyedShenava [a], Peyman Zare [a,b,c], Babak Mohamadi [a,c]

[a] Department of Electrical Engineering, Faculty of Engineering, University of Mohaghegh Ardabili, Ardabil, Iran
[b] University of Applied Science and Technology (UAST), Iran
[c] Ardabil Province Electricity Distribution Company (APED Co.), Ardabil, Iran

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ABSTRACT

Climate-neutral urban ecosystems increasingly depend on coordinated electricity–hydrogen–gas infrastructures capable of supporting hydrogen-powered mobility and high renewable penetration. However, existing sector-coupled models remain predominantly centralized, treat carriers as passive resources, and do not capture the interactive behavior of hydrogen public transport fleets under uncertainty. This work develops an integrated profit-oriented multi-agent scheduling framework that operationalizes electricity, hydrogen, and gas sectors as autonomous decision makers while enabling cross-vector exchanges through Power-to-hydrogen, hydrogen-to-power, hydrogen-to-gas, and gas-to-power pathways. A two-stage uncertainty strategy combining scenario-based stochastic modeling with robust optimization is employed to characterize variability in renewable generation, fleet hydrogen demand, market prices, and load conditions. The hybrid augmented lagrangian relaxation–alternating direction method of multipliers coordination algorithm was implemented to achieve iterative consensus with minimal information exchange. Simulation results reveal that hydrogen-centric conversions enhance multi-energy flexibility, with electricity- and hydrogen-agent profits increasing by up to 63.8 percent and 7.4 percent, respectively, compared with uncoordinated operation, while convergence iterations decrease by 20–25 percent. Expanding hydrogen storage from 25 to 45 kg raises electricity-sector profit from 67.3 to 82.0 USD and improves hydrogen-sector profit from 0.80 to 1.17 USD. The findings demonstrate that decentralized coordination and hydrogen-enabled transport fleets substantially strengthen operational resilience, economic efficiency, and cross-sectoral stability in climate-neutral cities.

Nomenclature

Abbreviation	Description	Abbreviation	Description
ADMM	Alternating Direction Method of Multipliers	ALR	Augmented Lagrangian Relaxation
ALR-ADMM	Hybrid Augmented Lagrangian Relaxation–Alternating Direction Method of Multipliers	ESS	Electricity Storage System
DG	Distributed Generator	HSS	Hydrogen Storage System
$H_2$2G	Hydrogen-to-Gas	SOC	State of Charge
G2P	Gas-to-Power	WTs	Wind Turbines
H_2	Hydrogen	LNG	Liquefied Natural Gas
$H_2$2P	Hydrogen-to-Power	UEH	Urban Energy Hubs
HP-UPTFs	Hydrogen-Powered Urban Public Transport Fleets	P2H_2	Power-to-Hydrogen
PVs	Photovoltaic	RES	Renewable Energy Sources

Note: Appendix A contains the complete list of all symbols and additional notation definitions.

* Corresponding author.
E-mail addresses: a.mohammadian@uma.ac.ir (A. Mohammadian), majiddejam@uma.ac.ir (A. Dejamkhooy), seyedshenava@uma.ac.ir (S. SeyedShenava), peymanzare@uma.ac.ir (P. Zare), b.mohamadi@uma.ac.ir (B. Mohamadi).

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