UiO : University of Oslo

Energy Autonomy in Local Flexibility: Taxonomy, Design, and Evaluation

University Paris-Dauphine- CEEM Conference

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Energy Transition

> "The energy transition is about more than just replacing fossil fuels with solar or wind power. It's also not just about upgrading the power grid. The real goal is smart energy management that puts power in the hands of users. It's about giving people the ability to make better energy choices and use energy in smarter, more sustainable ways."

Local Flexibility Markets

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Active Participation of Prosumers in the Local Energy System

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Need an effective distributed and autonomous energy management

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“

Autonomy ~ ?

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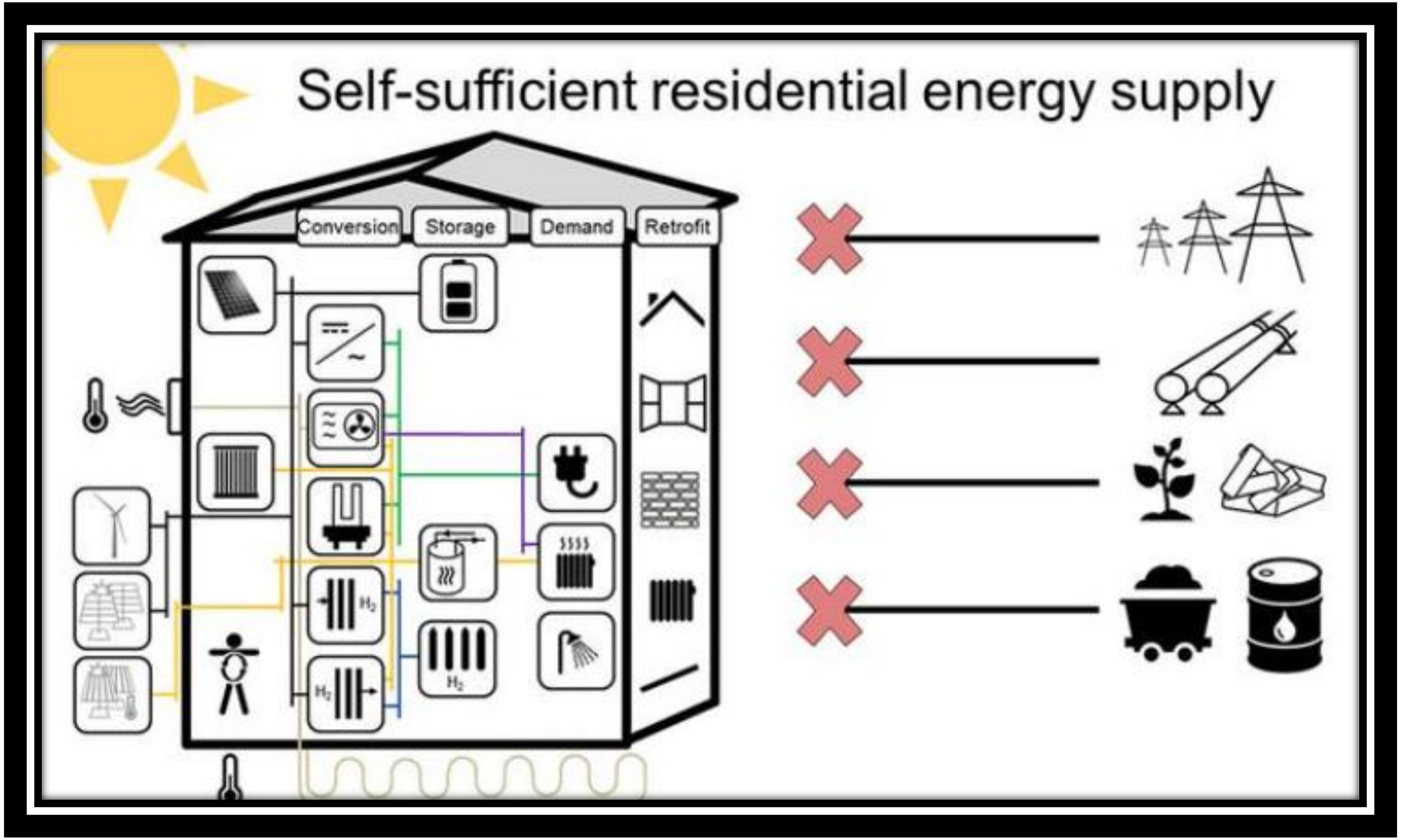
Self-sufficient residential energy supply
Conversion
Storage
Demand
Retrofit

[Ref 1]

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Autonomy ~ self-sufficiency

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“

Autonomy ~ self-sufficiency

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“

EU Clean Energy Package defines a renewable energy community as "autonomous" and under "effective control" of local members

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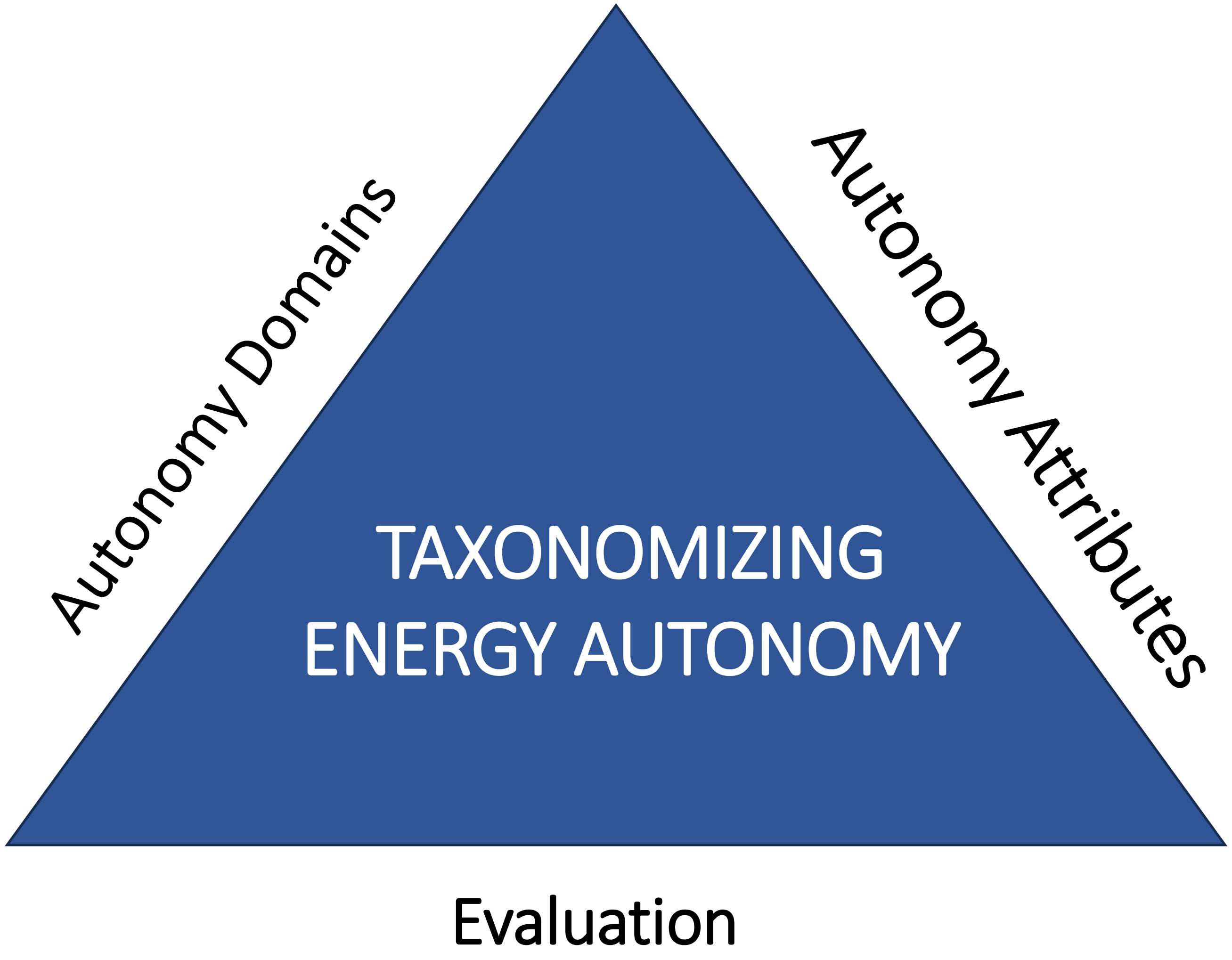
1. European Parliament and Council Directive (EU) 2019/944 of 5 June 2019 on common rules for the internal market in electricity and amending Directive 2012/27/EU [Ref 2].

Contributions



- ✓ Classifying energy autonomy strategies across multiple dimensions.
- ✓ Providing clearly defined attributes and metrics.
- ✓ Analyzing the autonomy configurations of key actors within local flexibility markets.

Autonomy Domains

COMMUNICATION

CONTROL

PHYSICAL DISTRIBUTION

Autonomy Attributes

Independent awareness & adaptation crucial.

Continuous learning needed to update behavior.

Effective communication for system navigation.

Autonomy balanced with oversight and system limitations.

Energy Autonomy

Energy Autonomy

“

- Definition: Capacity of an energy actor to function independently within a complex energy system.
- Reliance: Primarily on local energy generation, storage, and distribution capabilities.
- Autonomy Skills: Perceiving conditions, taking actions, ongoing learning, adaptive decision-making.
- Factors: Extent of autonomy influenced by interdependencies and system constraints.

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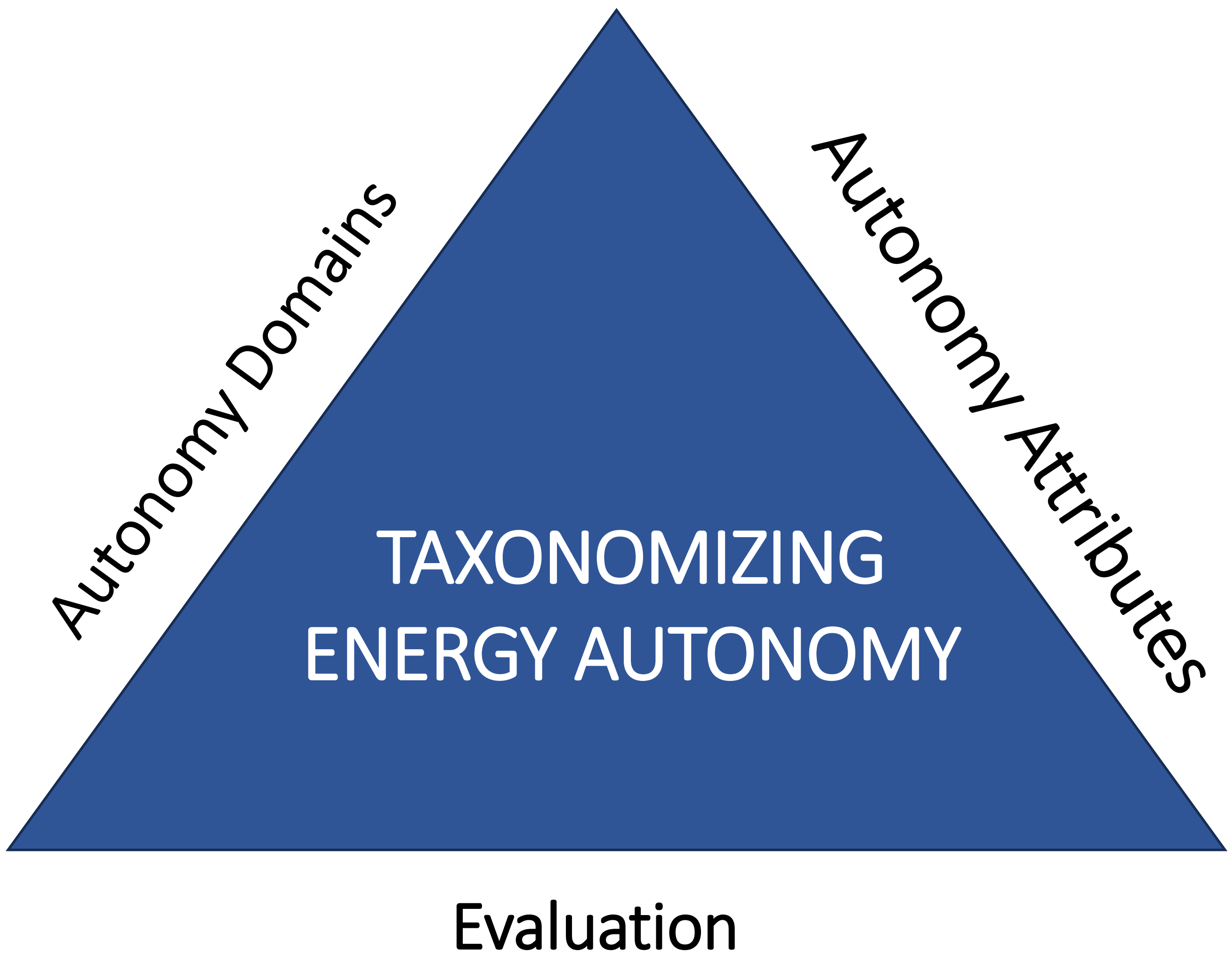
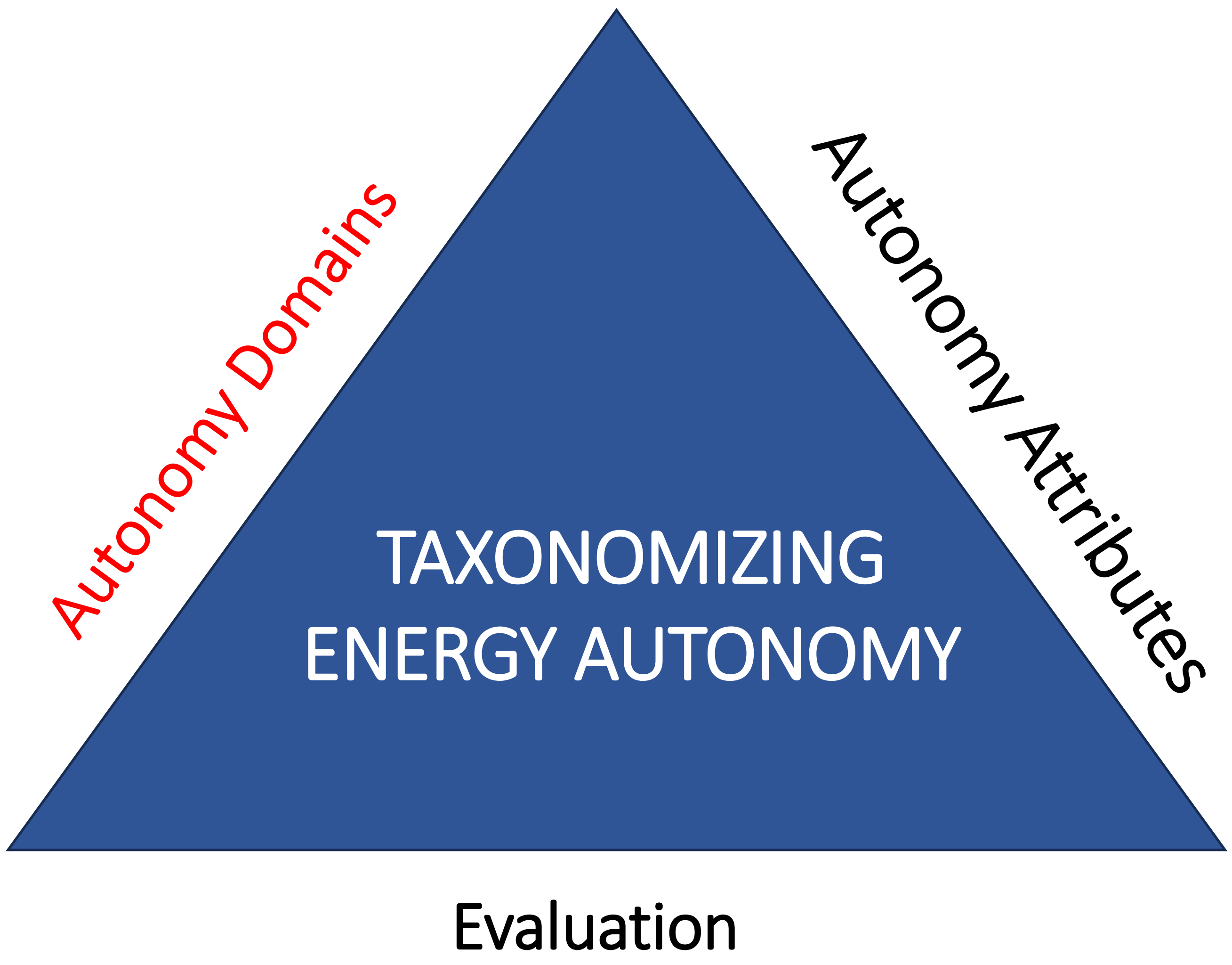
TAXONOMY

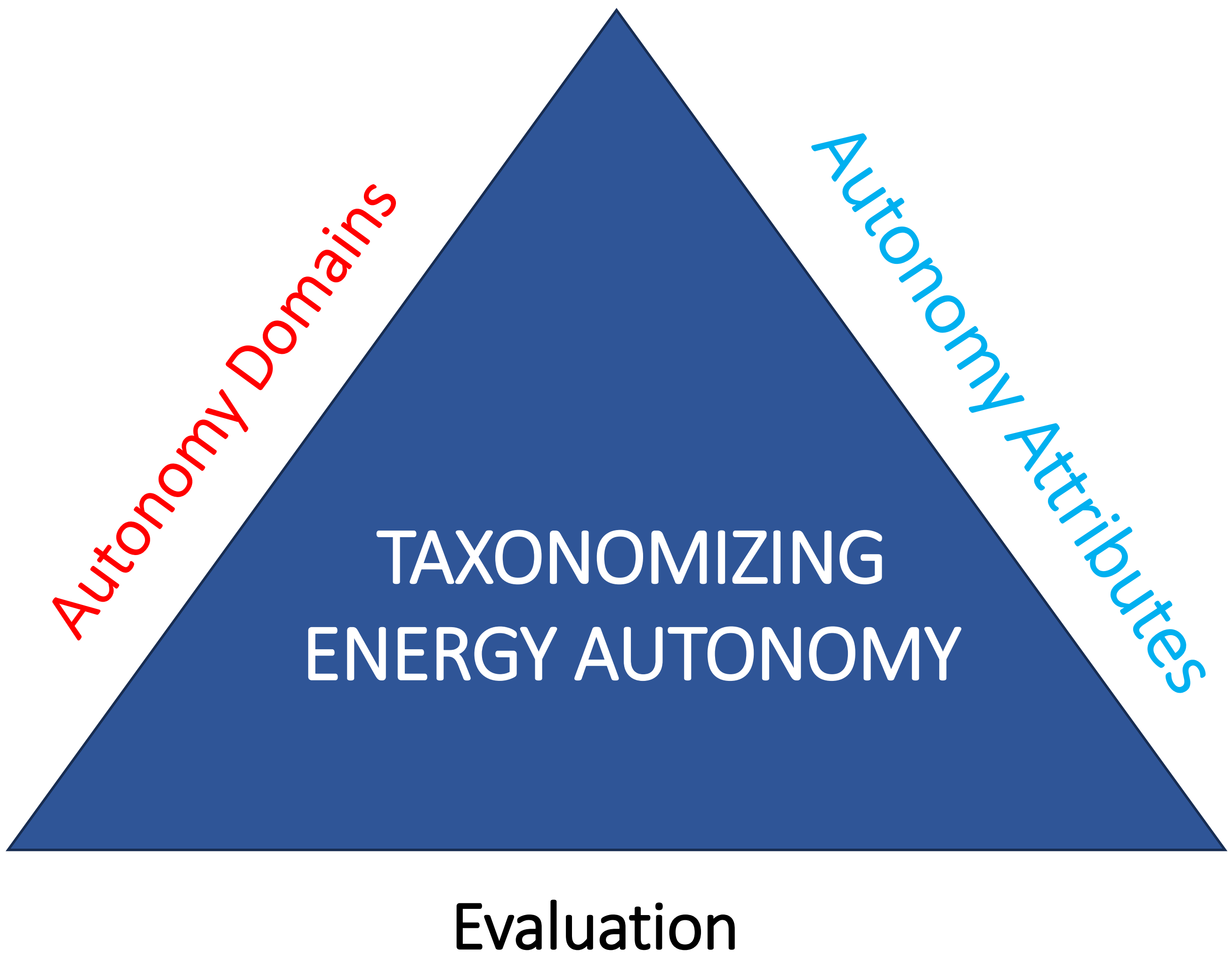

Autonomy Domains
Autonomy Attributes
TAXONOMIZING
ENERGY AUTONOMY
Evaluation



Communication

Control

Physical Distribution



Communication

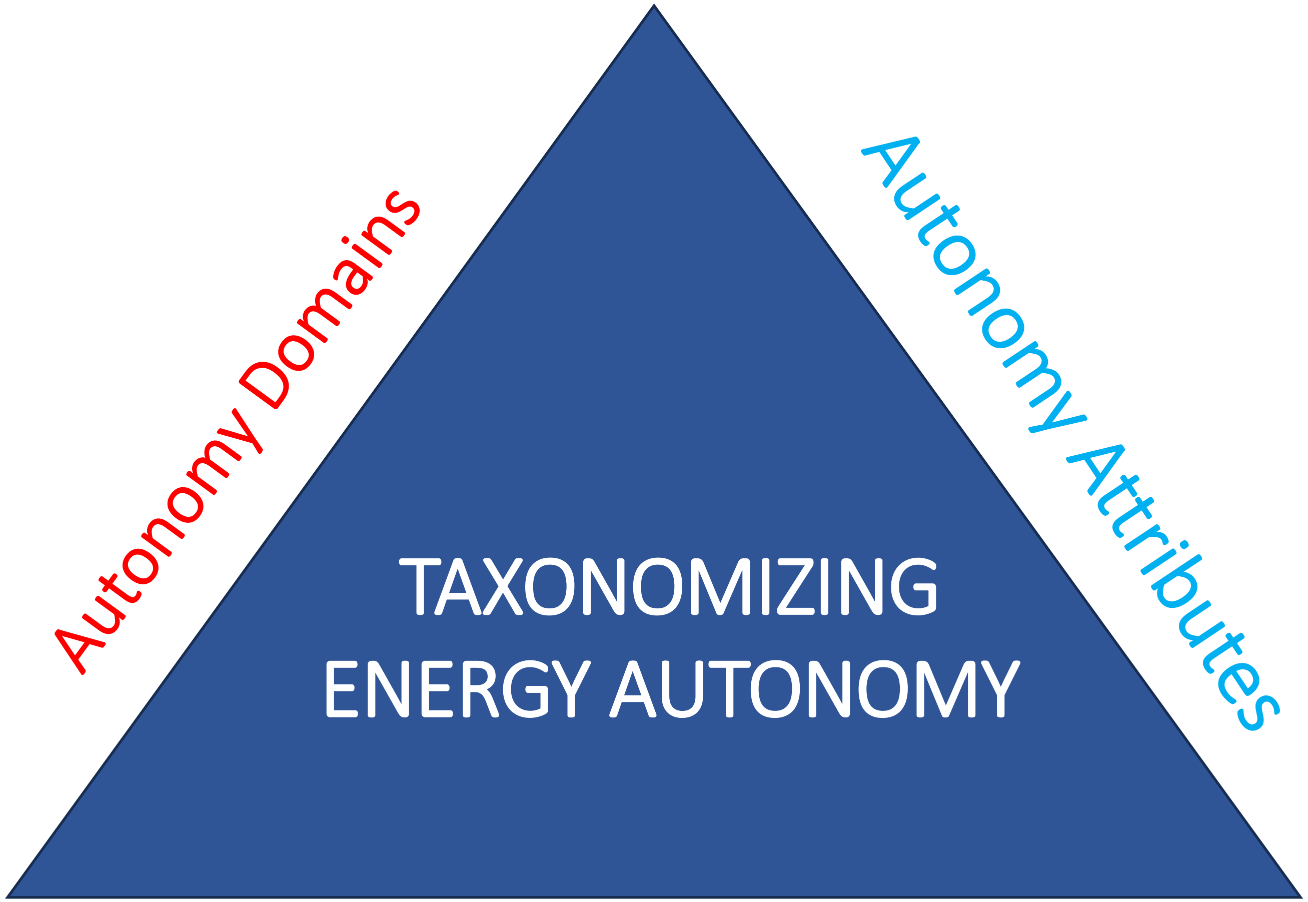
Control

Physical Distribution

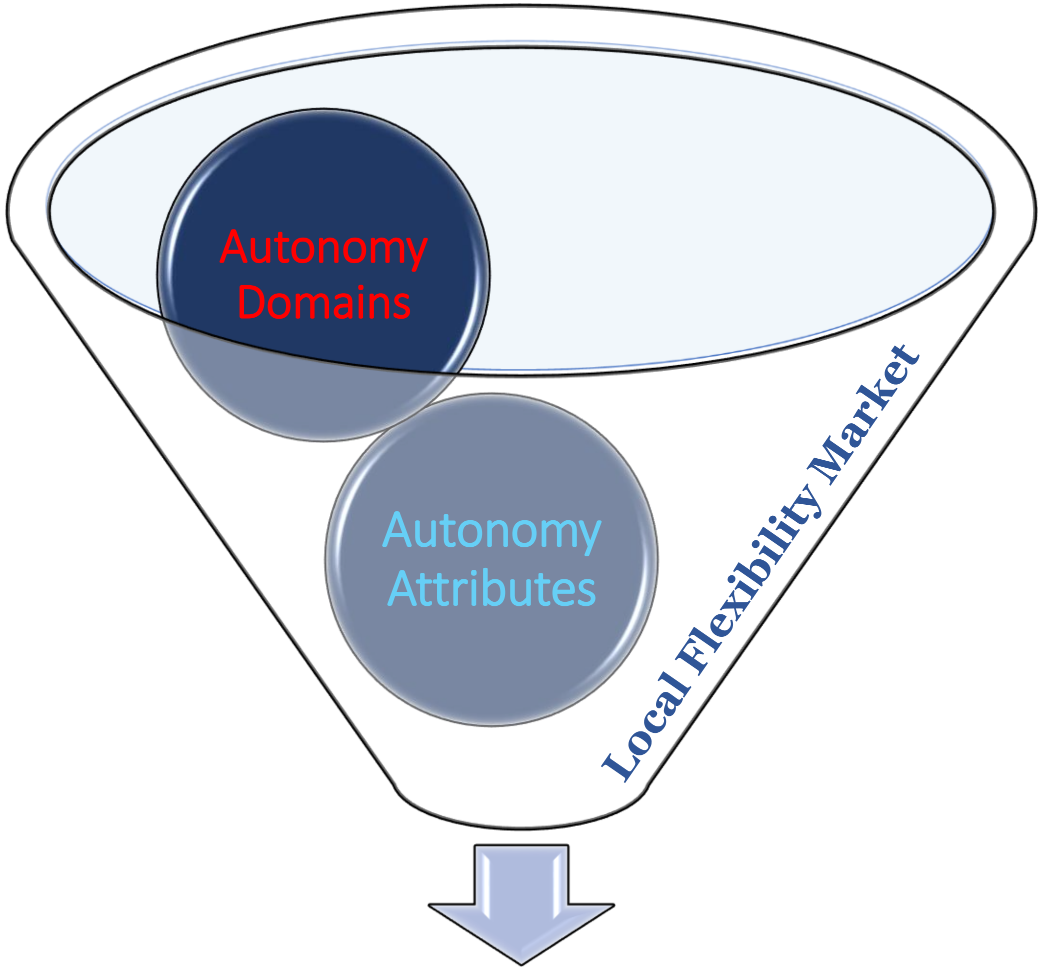
Independent Awareness & Adaptation

Continuous Learning

Effective Communication



Evaluation



Classification

Local Flexibility Market

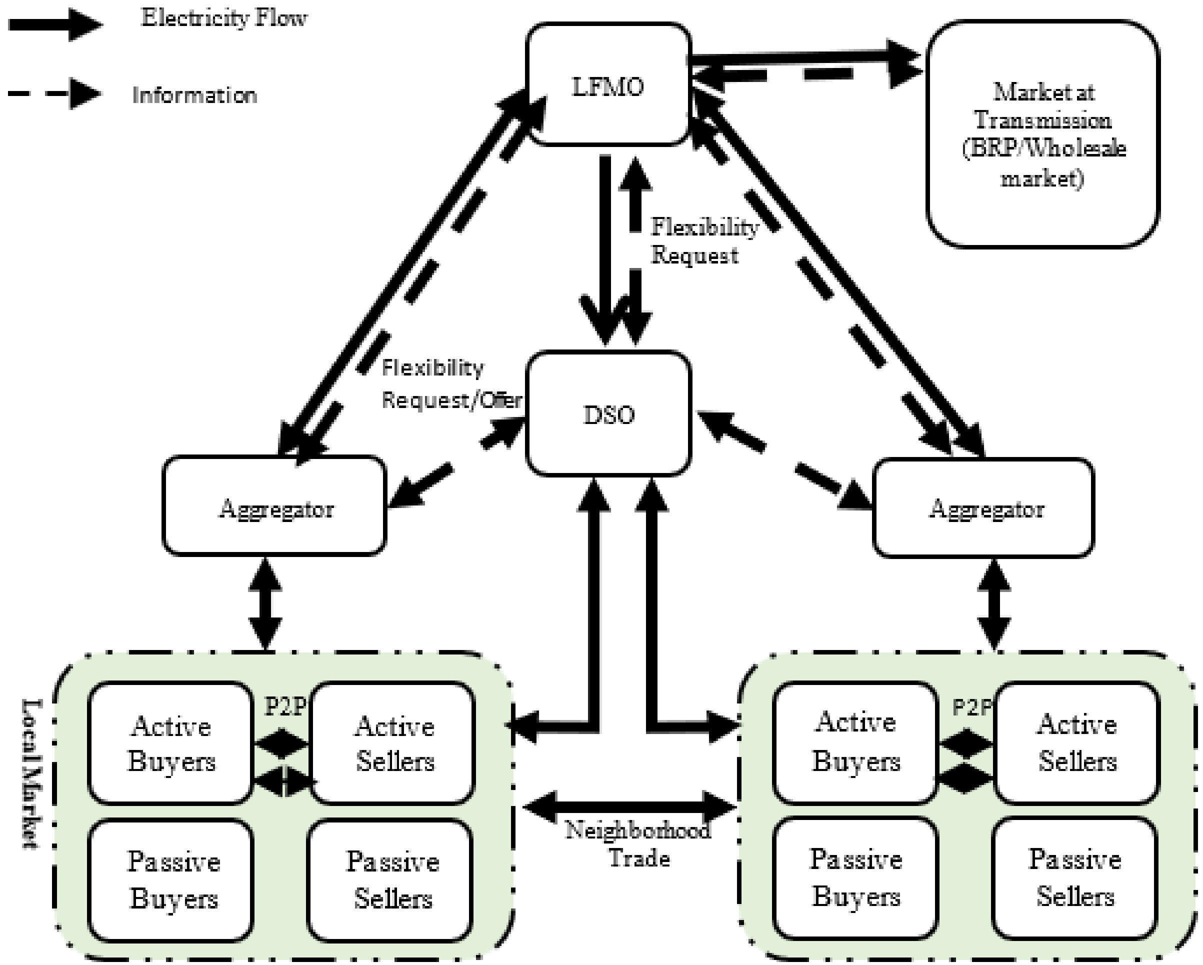


TABLE I
Energy autonomy taxonomy for the communication domain

Classification basis		ID	Explanation
Level of Information Sharing	Centralized	CI-C	Information is gathered and decisions are made centrally, with limited communication towards the autonomous system.
	Decentralized	CI-D	Information is distributed locally.
	Hybrid	CI-H	A combination of both.
Purpose of Communication	Instruction	CC-I	Instructions and directives are sent from a central authority to the autonomous system.
	Collaboration	CC-C	Information is exchanged to facilitate joint actions and achieve shared goals.
	Learning	CC-L	Communication enables the autonomous system to learn from the environment and adapt its behavior.

TABLE II

Energy autonomy taxonomy for the control domain

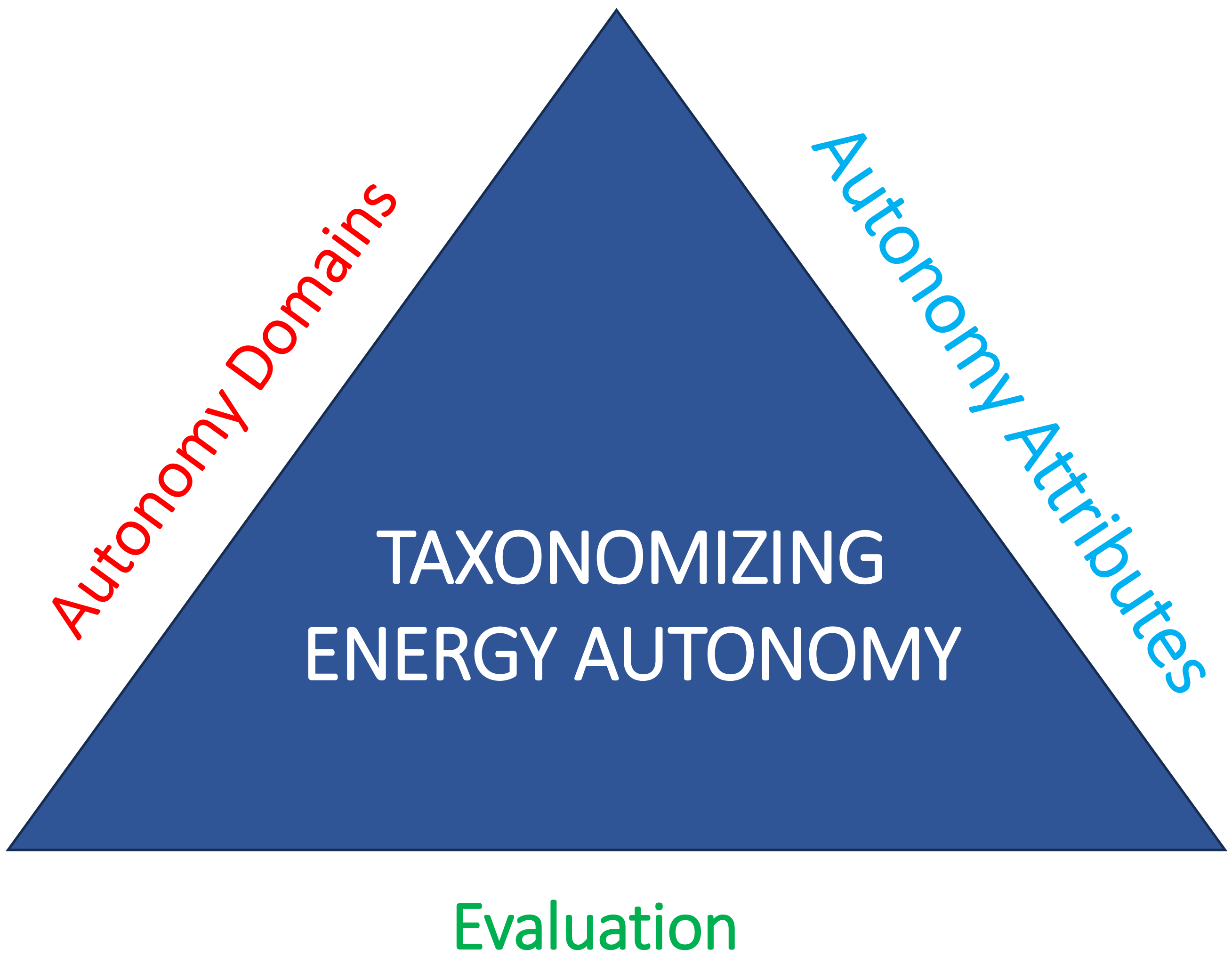
Classification basis		ID	Explanation
Supervised		GS	Operator retains full control authority. The operator sets goals and boundaries, while the autonomous system makes decisions within those constraints.
Shared	Negotiation	GS-N	Decision-making is distributed among multiple participants who engage in a negotiation process, often using economic-inspired protocols.
	Agreement	GS-A	This approach involves a "meta-coordination" process where participants collectively define the rules and goals.
Individual-driven		GI	System operates independently to maximize goals. The autonomous system makes all decisions and takes actions independently, without operator intervention.

TABLE III

Energy autonomy taxonomy for the physical domain

Classification basis		ID	Explanation
Level of Centralization	Centralized	PC-C	All actions occur in a central location.
	Decentralized	PC-D	Actions are distributed across multiple entities.
Resource Sharing	Collaborative	PR-C	Instructions and directives are sent from a central authority to the autonomous system.
	Independent	PR-I	Information is exchanged to facilitate joint actions and achieve shared goals.

EVALUATION CRITERIA


Autonomy Domains
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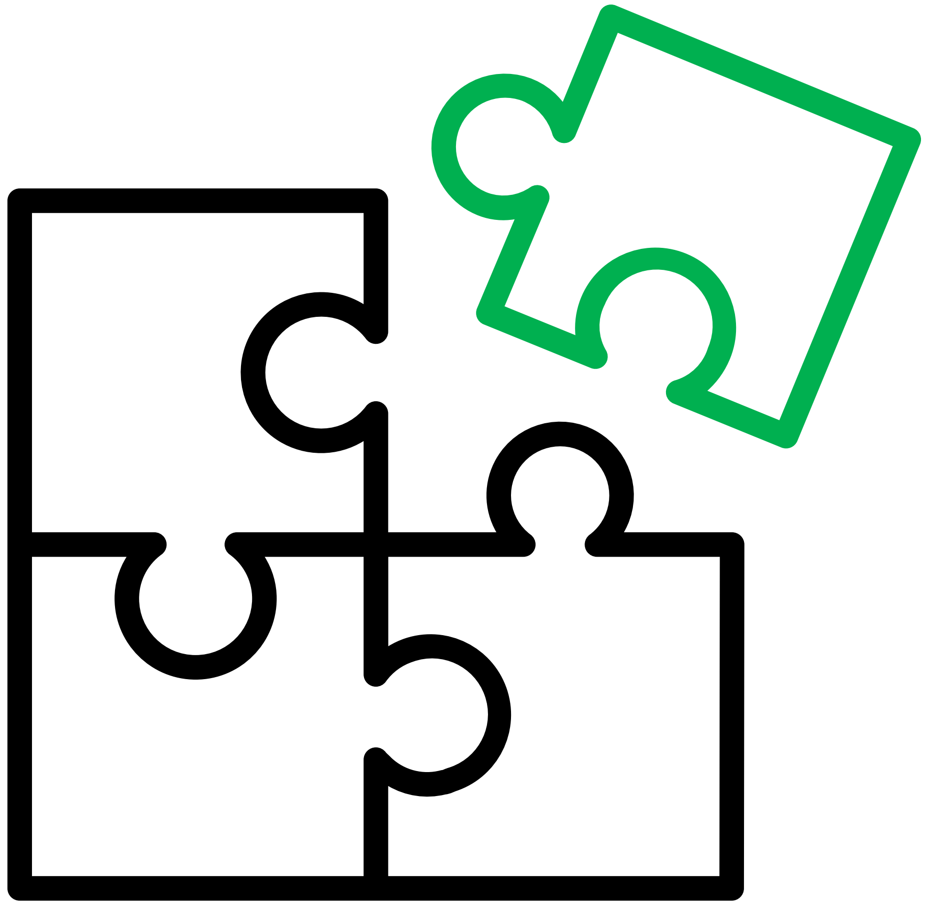
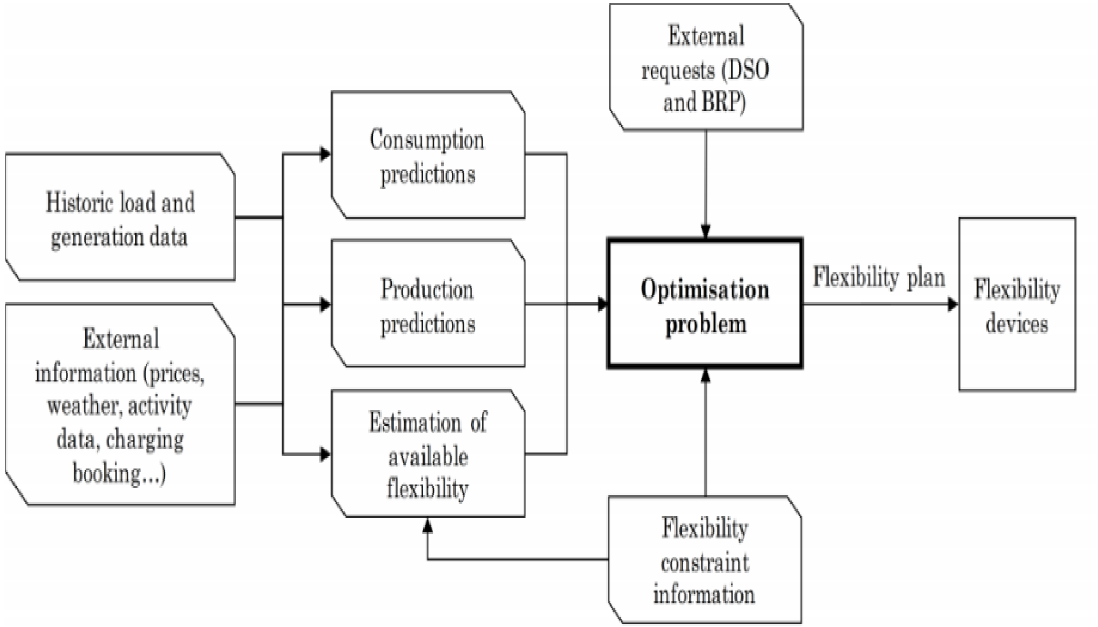
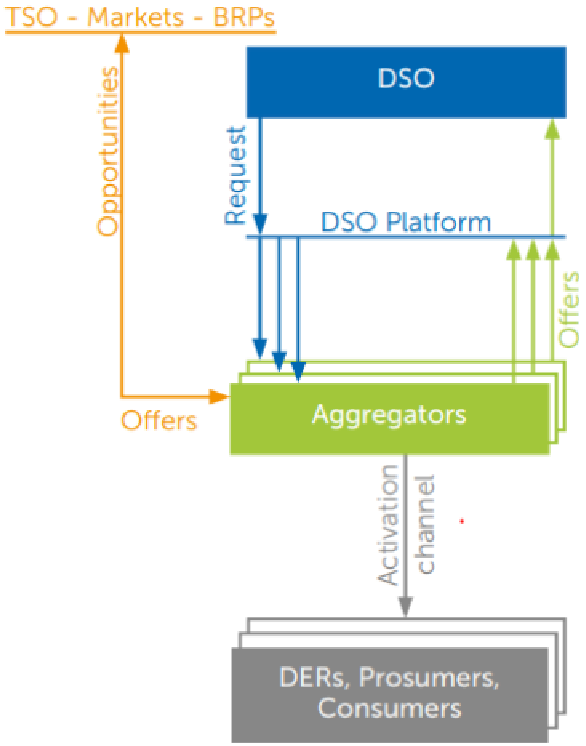


Example (Future work)



VS



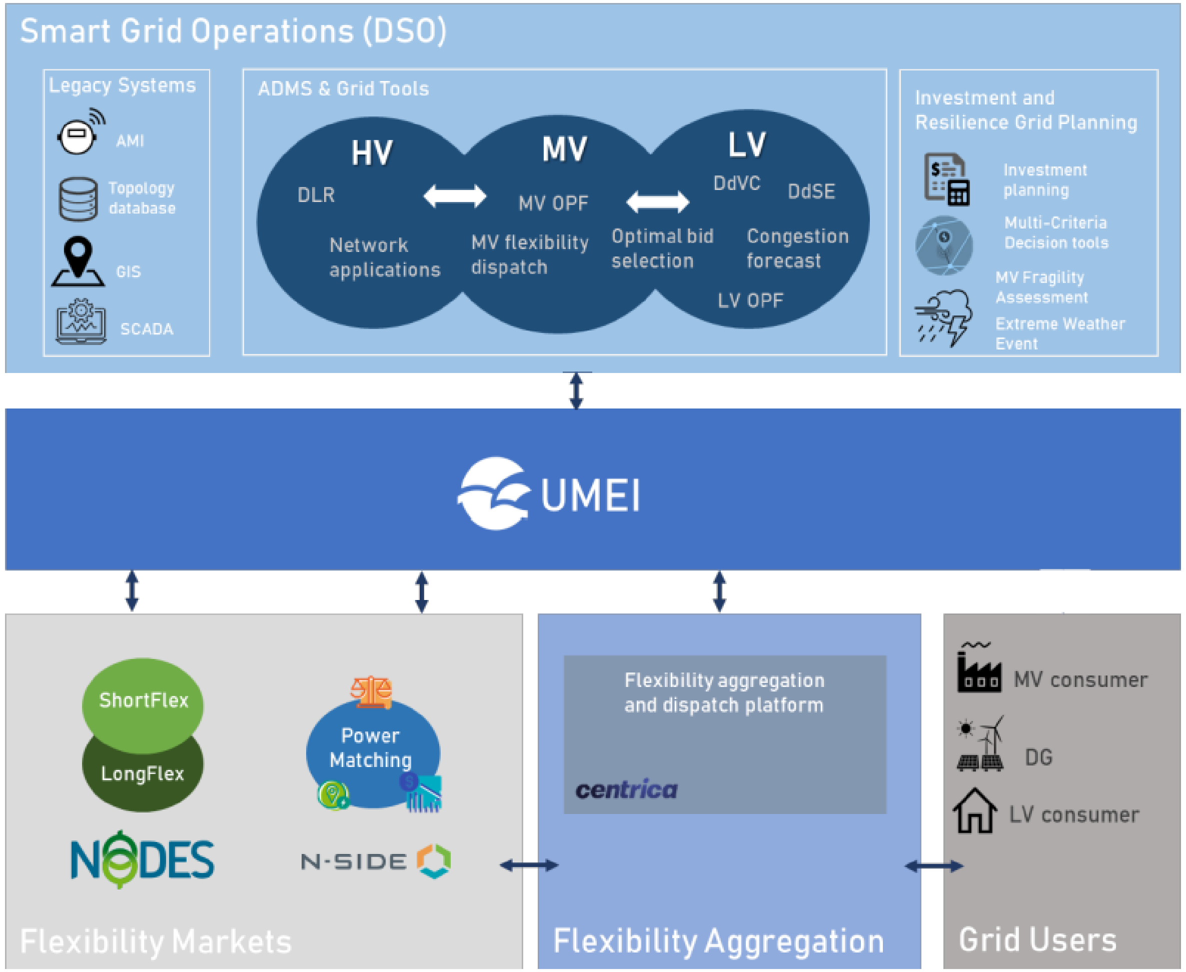
Local flexibility market algorithm of EMPOWER project [Ref 3]

FLEXGRID project's concept [Ref 4]

Centralized

Decentralized

Example (Future work)



UMEI and its compatibility with the market platforms [Ref 5]

Independent awareness & adaptation crucial.

Continuous learning needed to update behavior.

Effective communication for system navigation.

Autonomy balanced with oversight and system limitations.

TABLE VI
Design constraints.

Metric	Domain	Explanation
Computational Scalability	**G, C**	The capability to consistently fulfill ongoing requirements while adapting to an escalating volume of tasks.
Allocation Fairness	**P, C**	All participants share access to local infrastructure and contribute to its cost fairly, following established guidelines. Particular attention must be given to protect the interests of vulnerable groups, including the elderly, socially disadvantaged, and low-income customers.
Privacy	**C**	The process of data gathering, and analysis must comply with relevant regulations, such as the General Data Protection Regulation (GDPR) in Europe. Specific requirements should be established to govern the permissible limits for sharing behavioral and operational data between parties, ensuring the protection of privacy and data rights.
Service Reliability	**G**	The variance between the proposed bids and the actual power exchanges should align within a reasonable range as per network definitions and standards. This discrepancy encompasses forecasting errors, as well as other sources of errors within the system, such as communication failures or instances where the asset owner overrides commands.
Grid efficiency	**G**	In the presence of autonomous prosumers, network losses should not significantly exceed those observed in a centralized structure.

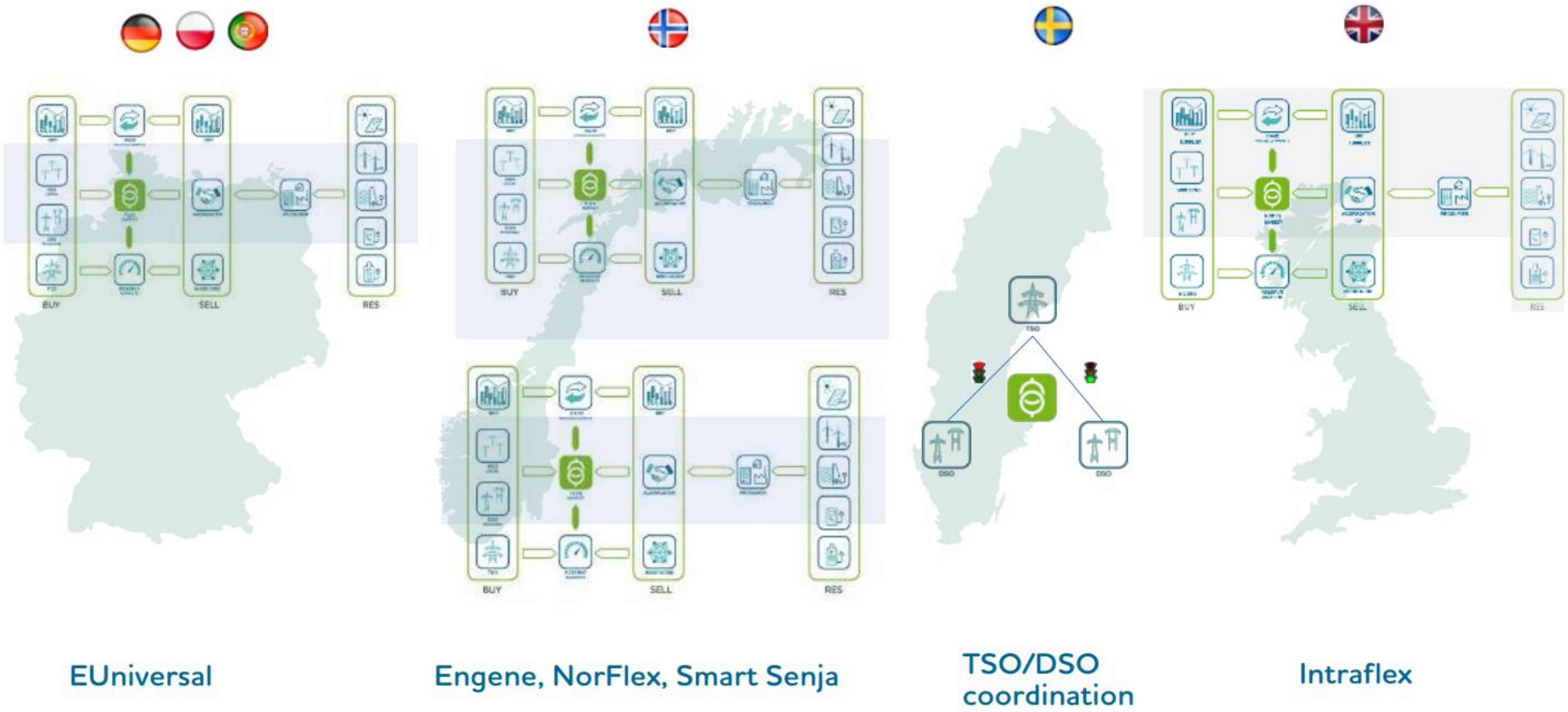
Communication (C) Control (G) Physical Distribution (P)

TABLE VI
Design constraints.

Metric	Domain	Explanation
Execution time	**C, G**	The execution time of market clearing should adhere to a reasonable timeframe in accordance with network definitions and standards.
System Observability	**C, G**	Measurements should be observable by the system operator in the most crucial nodes/lines, where the majority of energy flows, or in areas with the highest concentration of activity, or in critical areas with frequent outages or the presence of strategic customers (such as government headquarters, hospitals, etc.).
Network Reliability	**P, G**	The operation of the network should adhere to all applicable technical constraints, such as voltage limits, congestion management, and other relevant factors, to ensure reliable and efficient performance.

Communication (C) Control (G) Physical Distribution (P)

Example (Future work)



NODES integrated market design in Europe [Ref 6]

Future work

1- Assessing Autonomy in Successful EU Projects: A Comparative and Qualitative Study.

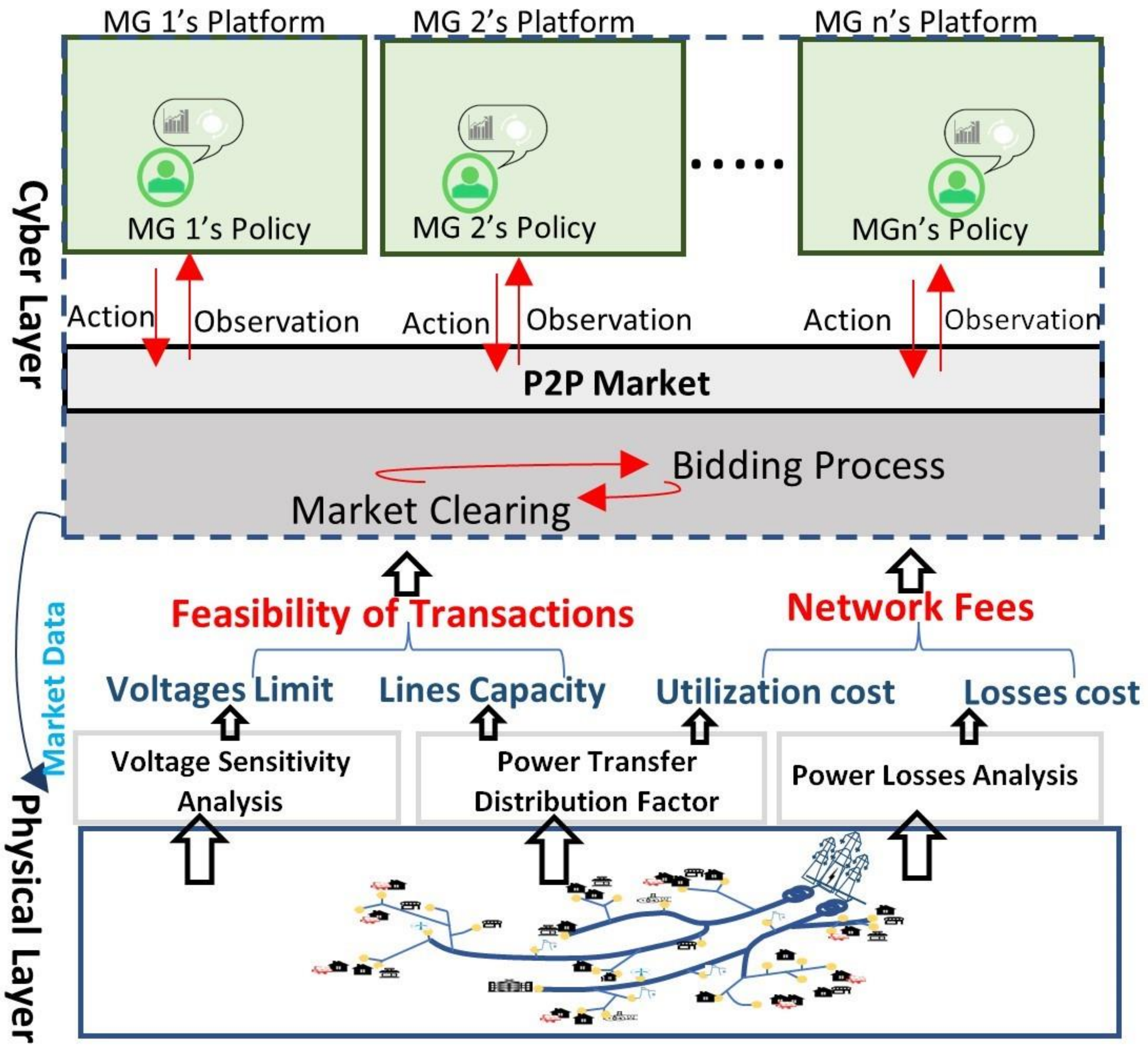
2- Develop Quantitative Metrics Derived from Qualitative Criteria in Table V.

3- Simulation based on case studies closely mirroring reality.

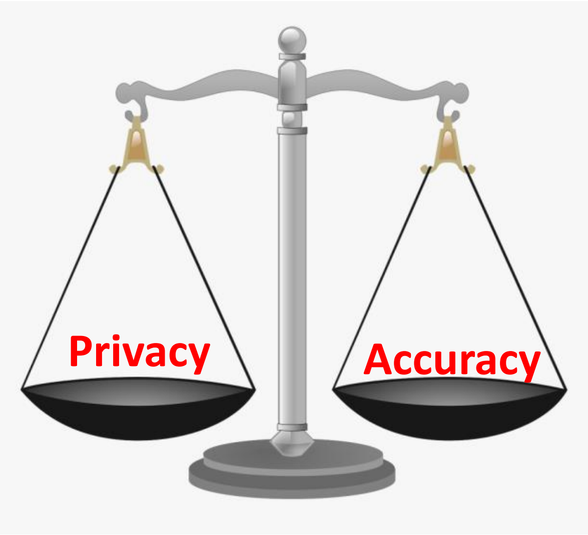
Our Related Works

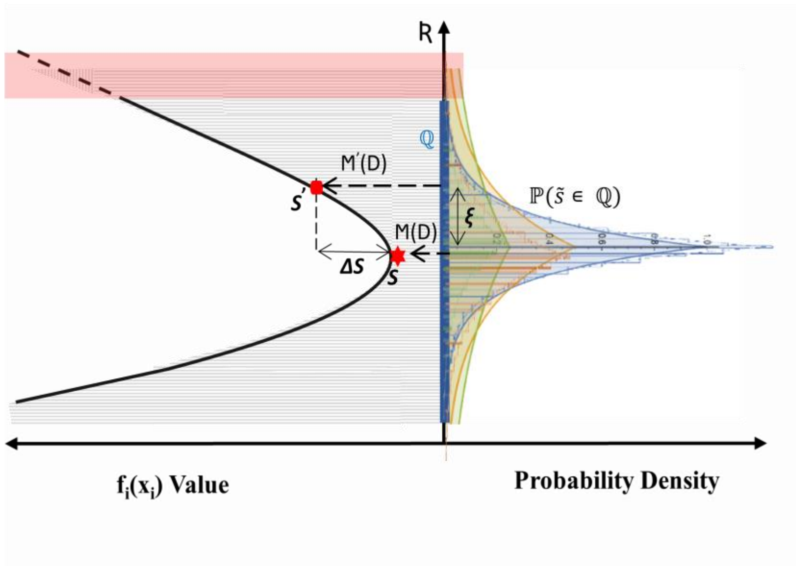
Autonomous Peer-to-Peer Energy Trading in Networked Microgrids: A Distributed Deep Reinforcement Learning Approach

2023 IEEE Innovative Smart Grid Technologies ISGT-Middle East
[Ref 7]

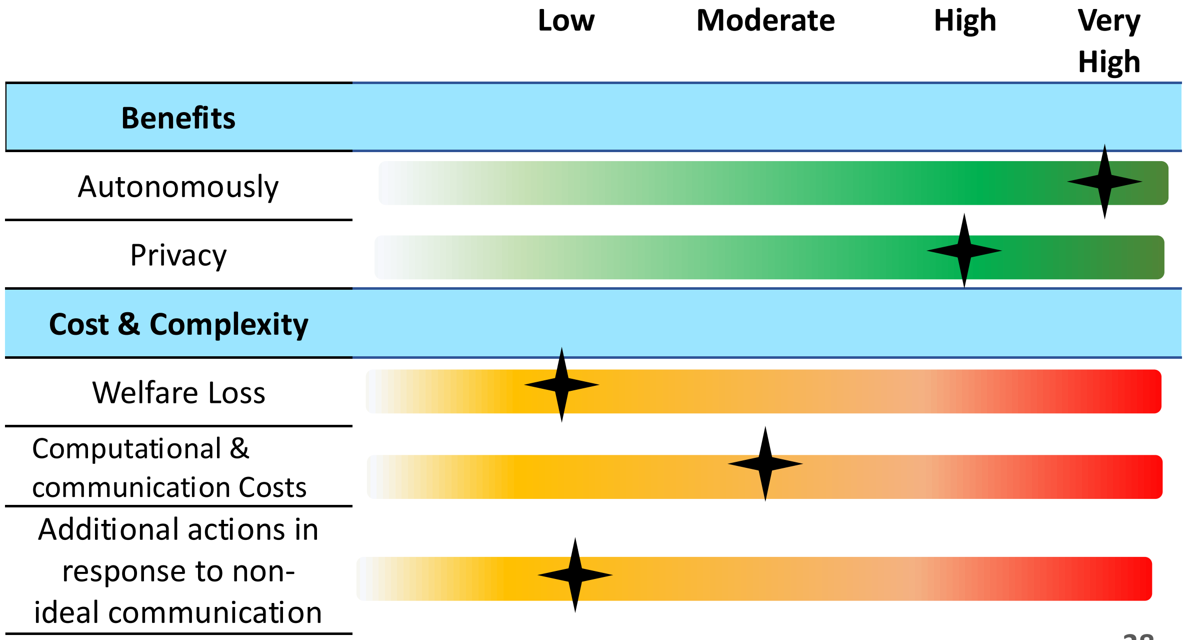


Safeguarding Energy Optimization of Prosumers via Secure and Privacy-Preserving Data Exchange





PSDO: Benefits Vs Cost & Complexity



References

Ref 1: Kleinebrahm, M., Weinand, J. M., Naber, E., McKenna, R., Ardone, A., & Fichtner, W. (2023). Two million European single-family homes could abandon the grid by 2050. *Joule*, *7*(11), 2485-2510.

Ref 2: European Parliament and Council Directive (EU) 2019/944 of 5 June 2019 on common rules for the internal market in electricity and amending Directive 2012/27/EU.

Ref 3: Olivella-Rosell, P., Lloret-Gallego, P., Munné-Collado, Í., Villafafila-Robles, R., Sumper, A., Ottessen, S.Ø., Rajasekharan, J. and Bremdal, B.A., 2018. Local flexibility market design for aggregators providing multiple flexibility services at distribution network level. Energies, 11(4), p.822.

Ref 4: https://interflex-h2020.com/results-and-achievements/local-flexibility-markets

Ref 5: https://euniversal.eu/wp-content/uploads/2022/05/EUniversal-WS-2022-final-1.pdf

Ref 6: https://smartinnovationnorway.com/wp-content/uploads/2022/09/20220920-NODES-FlexGrid-WS-low-res.pdf

Ref 7: Foroughi, M., Maharjan, S., Zhang, Y., & Eliassen, F. (2023, March). Autonomous peer-to-peer energy trading in networked microgrids: A distributed deep reinforcement learning approach. In 2023 IEEE PES Conference on Innovative Smart Grid Technologies-Middle East (ISGT Middle East) (pp. 1-5). IEEE.


Thank You