RESURSEFFEKTIV BEBYGGELSE

Byggnadsintegrerad energilagring och elektromobilitet för flexibla energigemenskaper: Ett svenskt perspektiv

Chang Su, PhD
chang.su@mdu.se
Biträdande lektor, Institutionen för teknikvetenskap
Mälardalens universitet

Introuduction

- Goal: Map the state of knowledge on Battery Energy Storage Systems (BESS) and Electric Vehicles (EVs) in energy communities with a focus on Swedish relevance.
- Sweden’s goal: Net-zero emissions by 2045 and a 100% renewable electricity system by 2040.
- The challenge: Managing the variability of renewable energy requires innovative flexibility solutions like aggregated BESS and EV charging.
- A synthesis study of **218** peer-reviewed scientific publications

RI.
SE

Key findings

- Research on energy communities has accelerated markedly since 2019, yet most studies prioritise PV–BESS at neighbourhood level; integrated electricity–heat–mobility solutions and multi-actor coordination remain comparatively scarce.
- Methods skewed to scenarios and optimization, as scenario analysis and MILP/LP dominate; empirical validation, long-term evidence and shared datasets are limited.
- EVs underused as flexibility resources. EVs are often modelled as loads rather than controllable assets (smart charging, V2B/V2G), leaving value-stacking opportunities underexplored.
- Environmental questions are studied more consistently than social justice, governance, and practical regulatory implementation.
- Sweden is still underrepresented in the literature, with only nine papers in the database explicitly involving Sweden

RI.
SE

Methodology

- Systematic Literature Review Process
- Review of 218 peer-reviewed publications from 2016 to 2025.
- Databases used: ScienceDirect and IEEE Xplore for targeted energy engineering and socio-technical research.
- Selection criteria: Focused on community-scale systems with distributed resources and flexibility services.
- Multi-dimensional categorization: Papers tagged across **Technical**, **Economic**, **Social**, and **Governance** (ESG) dimensions.

RI.
SE

Methodology

Research landscape on Energy Community: Keywords screening matrix

Database	Technical		Economic		ESG		
	Technologies	Scope	Indicators	Methods	Environ.	Social	Gov/regel.
ScienceDirect	PV,BESS EV HP,TES,CHP, DH, DC, FC	E prosumer Community E E transition	NPV IRR DPP LCOE SCR/SSR	MILP Scenarios ABM LCCA SD	Emit. reduc. E transition Climt. Chang. Local benefit Circular ecm.	E justice Com. engage. Social accep.	E demarcrocy E policy Reg barriers Market desig.
IEEE Xplore®	PV, BESS, EV Wind, CHP HP. Hydro	Microgrid Control desig. VPP E trading Grid integrat.	Sys cost min Ope cost min NPV Rev grid serv	MILP MPC RL/ML Stochastic Game theory	Emit. reduc. RE integra. Peak L reduc. E efficieny LCA	User behav. DR particip. Tech adop.	Grid codes Markt partici. Tariff

Much	Medium	Few

Methodology

Research landscape on Energy Community: Keywords screening

Database	Technical feasibility	
	Technologies	Scope
ScienceDirect	Rooftop PV system Battery Energy Storage System (community-owned) Electric Vehicles Heat Pumps,Termal Energy Storage, Fule Celss Combined Heat Power, District Heating/Cooling	Energy prosumer (residential buildings) Community Energy (residential/public buildings) Energy transition (neighbourhood)
IEEE Xplore®	PV, BESS, EV Wind, CHP HP. Hydro	Microgrid Power grid control design Virtual power plants Energy trading (peer-to-peer) Power grid integration

Much	Medium	Few

RI. SE

Methodology

Research landscape on Energy Community: Keywords screening

Database	Economic viability	
	Indicators	Methods
ScienceDirect	Net Present Value Internal Rate of Return Simple/Discounted Payback Period Levelised Cost of Energy Self Consumption Rate/Self Sufficient Rate	Mixed Integer Linear Programming Scenario analysis Agent Based Modelling Life Cycle Cost Analysis System Dynamics
IEEE Xplore®	Power system cost minimisation Power system operation cost minimisation Net Present Value Revenue from grid services	Mixed Integer Linear Programming Multi-Purpose Control Reinforcement Learing/Machine Learning Stochastic methods Game theory

Much	Medium	Few

RI. SE

Methodology

Research landscape on Energy Community: Keywords screening

Database	Environmental, Social, Governmental/regulatory aspects		
	Environ.	Social	Gov/regel.
ScienceDirect	Emission reduction Local benefits Energy transition Climate Change Circular economy	Energy justice Community engagement Social acceptance	Energy demarcrocy Energy policy Regulation barriers Market design
IEEE Xplore®	Emission reduction Renewable energy integration Peak load reduction Energy efficiency Life Cycle Analysis	User behavior Demand response participation Technology adoption	Grid codes Markt participation Tariff

Much	Medium	Few

RI. SE

Methodology: someting is new

- Innovative Analytical Framework: Combined traditional evidence synthesis with NLP-based text mining and topic modeling.
- Hybrid Human-Machine Analysis: Manual annotation: Expert review of a 40-paper sample to establish "ground truth".
- NLP-powered classification: Automated categorization of the remaining papers using supervised algorithms and topic modeling.

RI.
SE

Deliverable: knowledge database

Description of the database and how to use it:

The synthesis study generated a compiled database which contains a total of 218 scientific research papers focusing on the topic of **Energy Communities**. In the database, each entry (or row) represents a unique paper, accompanied by a range of bibliographic information and detailed thematic labels. The dataset includes 64 columns in total. The first set of columns records bibliometric and descriptive information such as:

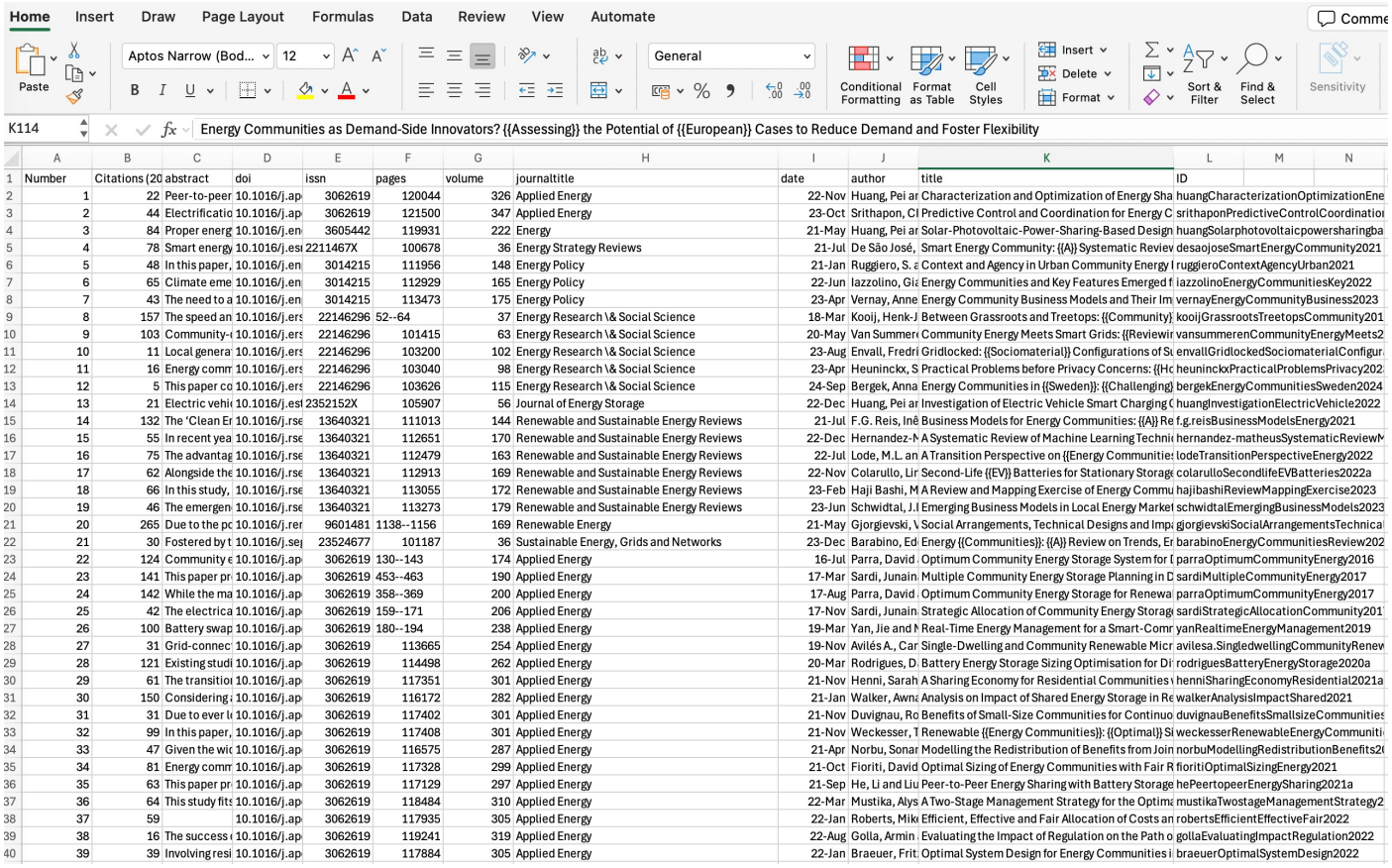
Paper Number (paper index in the dataset), **Citations** (number of times the paper has been cited, until 2025-05-23), **Abstract**, **DOI**,**ISSN**, **Pages**, **Volume**, **Journal title**, **Publication date**, **Authors**, **Paper title**.

Starting from the column "**PV**", the remaining columns serve as keyword-based binary indicators describing the research scope, methodology, and other characteristics of the papers. For these keyword columns:

- A value of 1 indicates that the paper explicitly covers the topic or method described by the keyword.
- A value of 0 indicates that the topic is not addressed in the paper.

RI.
SE

Deliverable: knowledge database



Home Insert Draw Page Layout Formulas Data Review View Automate

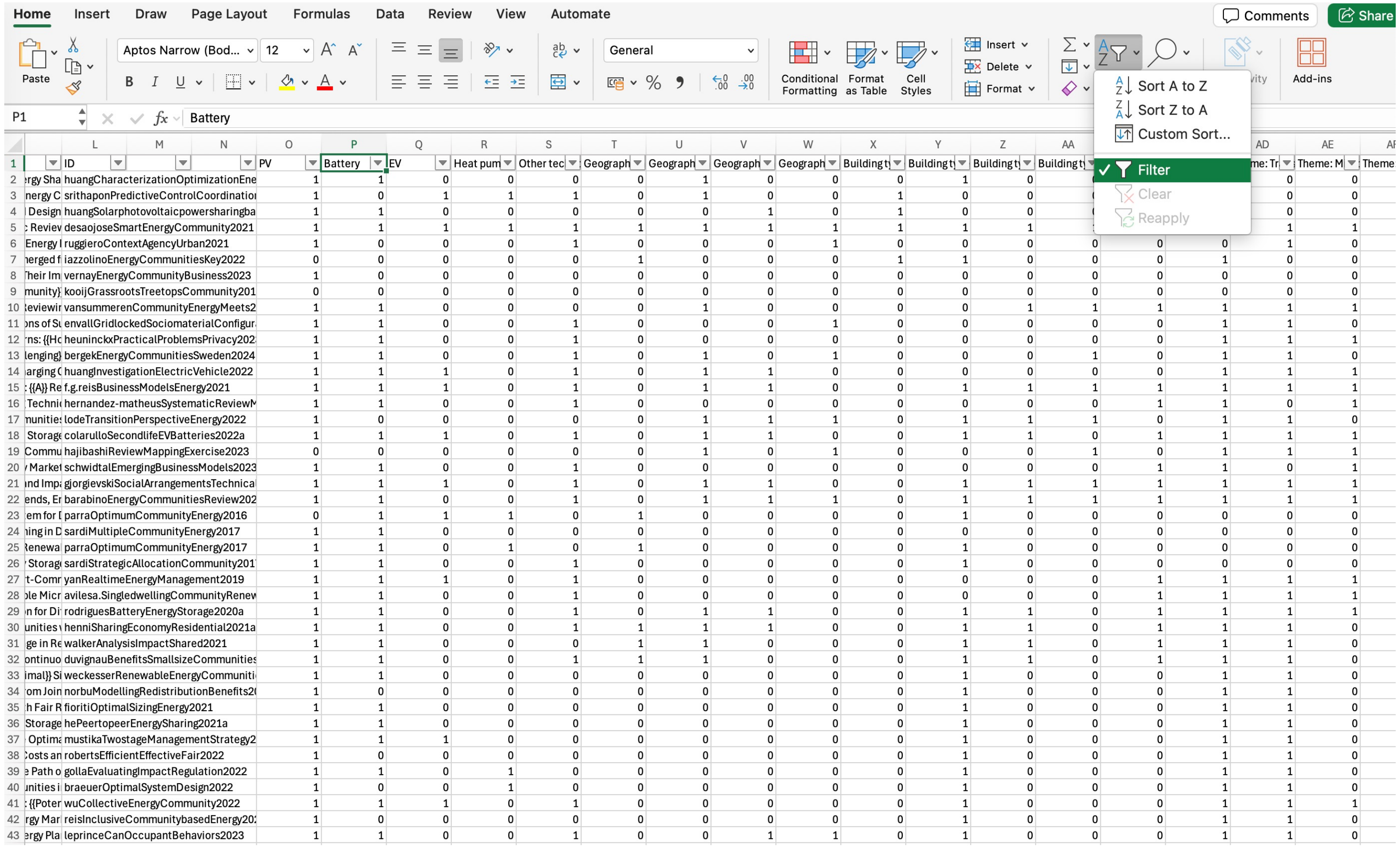
Paste · Aptos Narrow (Bod... · 12 · General · Conditional Formatting · Format as Table · Cell Styles · Insert · Delete · Format · Sort & Filter · Find & Select · Sensitivity

K114 — Energy Communities as Demand-Side Innovators? {{Assessing}} the Potential of {{European}} Cases to Reduce Demand and Foster Flexibility

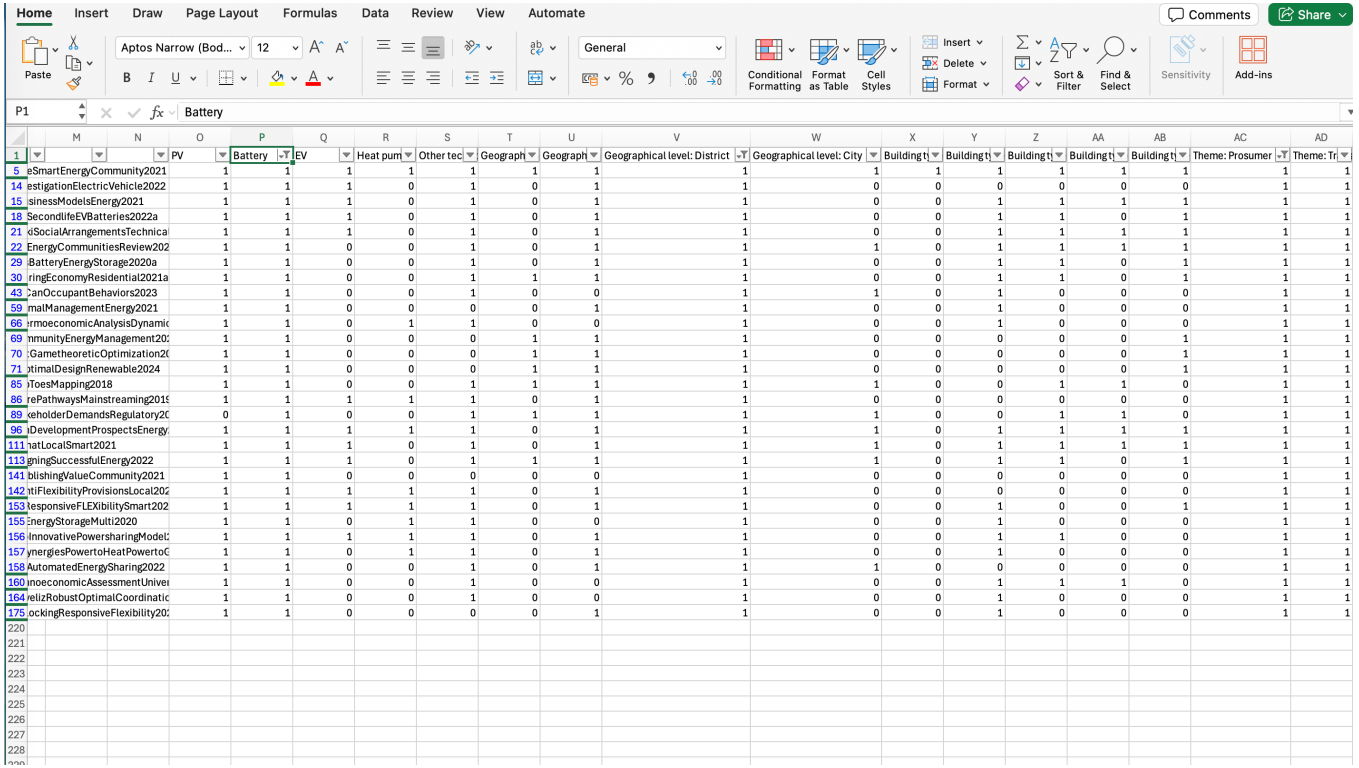
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Number	Citations (20	abstract	doi	issn	pages	volume	journaltitle	date	author	title	ID		
2	1	22	Peer-to-peer	10.1016/j.ap	3062619	120044	326	Applied Energy	22-Nov	Huang, Pei ar	Characterization and Optimization of Energy Sha	huangCharacterizationOptimizationEne		
3	2	44	Electrificatio	10.1016/j.ap	3062619	121500	347	Applied Energy	23-Oct	Srithapon, Cl	Predictive Control and Coordination for Energy C	srithaponPredictiveControlCoordinatio		
4	3	84	Proper energ	10.1016/j.en	3605442	119931	222	Energy	21-May	Huang, Pei ar	Solar-Photovoltaic-Power-Sharing-Based Design	huangSolarphotovoltaicpowersharingba		
5	4	78	Smart energy	10.1016/j.esi	2211467X	100678	36	Energy Strategy Reviews	21-Jul	De São José,	Smart Energy Community: {{A}} Systematic Reviev	desaojoseSmartEnergyCommunity2021		
6	5	48	In this paper,	10.1016/j.en	3014215	111956	148	Energy Policy	21-Jan	Ruggiero, S. a	Context and Agency in Urban Community Energy I	ruggieroContextAgencyUrban2021		
7	6	65	Climate eme	10.1016/j.en	3014215	112929	165	Energy Policy	22-Jun	Iazzolino, Gia	Energy Communities and Key Features Emerged f	iazzolinoEnergyCommunitiesKey2022		
8	7	43	The need to a	10.1016/j.en	3014215	113473	175	Energy Policy	23-Apr	Vernay, Anne	Energy Community Business Models and Their Im	vernayEnergyCommunityBusiness2023		
9	8	157	The speed an	10.1016/j.ers	22146296	52--64	37	Energy Research \& Social Science	18-Mar	Kooij, Henk-J	Between Grassroots and Treetops: {{Community}	kooijGrassrootsTreetopsCommunity201		
10	9	103	Community-(	10.1016/j.ers	22146296	101415	63	Energy Research \& Social Science	20-May	Van Summer(	Community Energy Meets Smart Grids: {{Reviewir	vansummerenCommunityEnergyMeets2		
11	10	11	Local genera	10.1016/j.ers	22146296	103200	102	Energy Research \& Social Science	23-Aug	Envall, Fredri	Gridlocked: {{Sociomaterial}} Configurations of Su	envallGridlockedSociomaterialConfigur		
12	11	16	Energy comm	10.1016/j.ers	22146296	103040	98	Energy Research \& Social Science	23-Apr	Heuninckx, S	Practical Problems before Privacy Concerns: {{Hc	heuninckxPracticalProblemsPrivacy202		
13	12	5	This paper co	10.1016/j.ers	22146296	103626	115	Energy Research \& Social Science	24-Sep	Bergek, Anna	Energy Communities in {{Sweden}}: {{Challenging}	bergekEnergyCommunitiesSweden2024		
14	13	21	Electric vehi	10.1016/j.est	2352152X	105907	56	Journal of Energy Storage	22-Dec	Huang, Pei ar	Investigation of Electric Vehicle Smart Charging (	huangInvestigationElectricVehicle2022		
15	14	132	The 'Clean Er	10.1016/j.rse	13640321	111013	144	Renewable and Sustainable Energy Reviews	21-Jul	F.G. Reis, Ine	Business Models for Energy Communities: {{A}} Re	f.g.reisBusinessModelsEnergy2021		
16	15	55	In recent yea	10.1016/j.rse	13640321	112651	170	Renewable and Sustainable Energy Reviews	22-Dec	Hernandez-M	A Systematic Review of Machine Learning Techni	hernandez-matheusSystematicReviewM		
17	16	75	The advantag	10.1016/j.rse	13640321	112479	163	Renewable and Sustainable Energy Reviews	22-Jul	Lode, M.L. an	A Transition Perspective on {{Energy Communitie	lodeTransitionPerspectiveEnergy2022		
18	17	62	Alongside the	10.1016/j.rse	13640321	112913	169	Renewable and Sustainable Energy Reviews	22-Nov	Colarullo, Lir	Second-Life {{EV}} Batteries for Stationary Storage	colarulloSecondlifeEVBatteries2022a		
19	18	66	In this study,	10.1016/j.rse	13640321	113055	172	Renewable and Sustainable Energy Reviews	23-Feb	Haji Bashi, M	A Review and Mapping Exercise of Energy Commu	hajibashiReviewMappingExercise2023		
20	19	46	The emergen	10.1016/j.rse	13640321	113273	179	Renewable and Sustainable Energy Reviews	23-Jun	Schwidtal, J.I	Emerging Business Models in Local Energy Marke	schwidtalEmergingBusinessModels2023		
21	20	265	Due to the pc	10.1016/j.rer	9601481	1138--1156	169	Renewable Energy	21-May	Gjorgievski, V	Social Arrangements, Technical Designs and Imp	giorgievskiSocialArrangementsTechnica		
22	21	30	Fostered by t	10.1016/j.se	23524677	101187	36	Sustainable Energy, Grids and Networks	23-Dec	Barabino, Ed	Energy {{Communities}}: {{A}} Review on Trends, Er	barabinoEnergyCommunitiesReview202		
23	22	124	Community e	10.1016/j.ap	3062619	130--143	174	Applied Energy	16-Jul	Parra, David	Optimum Community Energy Storage System for I	parraOptimumCommunityEnergy2016		
24	23	141	This paper pr	10.1016/j.ap	3062619	453--463	190	Applied Energy	17-Mar	Sardi, Junain	Multiple Community Energy Storage Planning in D	sardiMultipleCommunityEnergy2017		
25	24	142	While the ma	10.1016/j.ap	3062619	358--369	200	Applied Energy	17-Aug	Parra, David	Optimum Community Energy Storage for Renewa	parraOptimumCommunityEnergy2017		
26	25	42	The electrica	10.1016/j.ap	3062619	159--171	206	Applied Energy	17-Nov	Sardi, Junain	Strategic Allocation of Community Energy Storag	sardiStrategicAllocationCommunity201		
27	26	100	Battery swap	10.1016/j.ap	3062619	180--194	238	Applied Energy	19-Mar	Yan, Jie and M	Real-Time Energy Management for a Smart-Comr	yanRealtimeEnergyManagement2019		
28	27	31	Grid-connec	10.1016/j.ap	3062619	113665	254	Applied Energy	19-Nov	Avilés A., Car	Single-Dwelling and Community Renewable Micr	avilesa.SingledwellingCommunityRenew		
29	28	121	Existing studi	10.1016/j.ap	3062619	114498	262	Applied Energy	20-Mar	Rodrigues, D	Battery Energy Storage Sizing Optimisation for Di	rodriguesBatteryEnergyStorage2020a		
30	29	61	The transitio	10.1016/j.ap	3062619	117351	301	Applied Energy	21-Nov	Henni, Sarah	A Sharing Economy for Residential Communities	henniSharingEconomyResidential2021a		
31	30	150	Considering a	10.1016/j.ap	3062619	116172	282	Applied Energy	21-Jan	Walker, Awn(	Analysis on Impact of Shared Energy Storage in Re	walkerAnalysisImpactShared2021		
32	31	31	Due to ever l	10.1016/j.ap	3062619	117402	301	Applied Energy	21-Nov	Duvignau, Ro	Benefits of Small-Size Communities for Continuo	duvignauBenefitsSmallsizeCommunities		
33	32	99	In this paper,	10.1016/j.ap	3062619	117408	301	Applied Energy	21-Nov	Weckesser, T	Renewable {{Energy Communities}}: {{Optimal}} Si	weckesserRenewableEnergyCommuniti		
34	33	47	Given the wic	10.1016/j.ap	3062619	116575	287	Applied Energy	21-Apr	Norbu, Sonar	Modelling the Redistribution of Benefits from Join	norbuModellingRedistributionBenefits2(		
35	34	81	Energy comm	10.1016/j.ap	3062619	117328	299	Applied Energy	21-Oct	Fioriti, David	Optimal Sizing of Energy Communities with Fair R	fioritiOptimalSizingEnergy2021		
36	35	63	This paper pr	10.1016/j.ap	3062619	117129	297	Applied Energy	21-Sep	He, Li and Liu	Peer-to-Peer Energy Sharing with Battery Storage	hePeertopeerEnergySharing2021a		
37	36	64	This study fits	10.1016/j.ap	3062619	118484	310	Applied Energy	22-Mar	Mustika, Alys	A Two-Stage Management Strategy for the Optima	mustikaTwostageManagementStrategy2		
38	37	59		10.1016/j.ap	3062619	117935	305	Applied Energy	22-Jan	Roberts, Mik	Efficient, Effective and Fair Allocation of Costs an	robertsEfficientEffectiveFair2022		
39	38	16	The success (	10.1016/j.ap	3062619	119241	319	Applied Energy	22-Aug	Golla, Armin	Evaluating the Impact of Regulation on the Path o	gollaEvaluatingImpactRegulation2022		
40	39	39	Involving resi	10.1016/j.ap	3062619	117884	305	Applied Energy	22-Jan	Braeuer, Frit	Optimal System Design for Energy Communities i	braeuerOptimalSystemDesign2022		

RI. SE

Deliverable: knowledge database



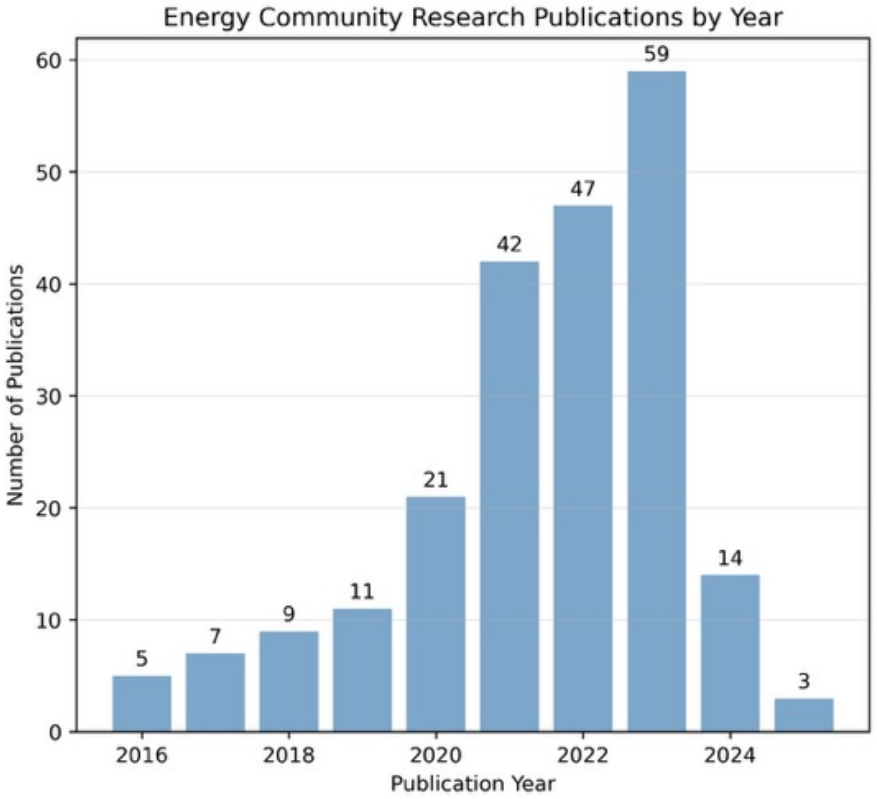
Deliverable: knowledge database



	PV	Battery	EV	Heat pum	Other tec	Geograph	Geograph	Geographical level: District	Geographical level: City	Buildingt	Buildingt	Buildingt	Buildingt	Buildingt	Theme: Prosumer	Theme: Tr
5	eSmartEnergyCommunity2021	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	estigationElectricVehicle2022	1	1	1	0	1	0	1	1	0	0	0	0	0	1	1
15	sinessModelsEnergy2021	1	1	1	0	1	0	1	1	0	0	1	1	1	1	1
18	SecondlifeEVBatteries2022a	1	1	1	0	1	0	1	1	0	0	1	1	0	1	1
21	dSocialArrangementsTechnica	1	1	1	0	1	0	1	1	0	0	1	1	1	1	1
22	EnergyCommunitiesReview202	1	1	0	0	1	0	1	1	1	0	1	1	1	1	1
29	BatteryEnergyStorage2020a	1	1	0	0	1	0	1	1	0	0	1	1	0	1	1
30	ringEconomyResidential2021a	1	1	0	0	1	1	1	1	0	0	1	1	0	1	1
43	anOccupantBehaviors2023	1	1	0	0	1	0	0	1	0	0	1	0	0	0	1
59	malManagementEnergy2021	1	1	0	0	0	0	1	1	0	0	1	0	0	0	1
66	rmoeconomicAnalysisDynamic	1	1	0	1	1	0	0	1	0	0	1	0	0	0	1
69	mmunityEnergyManagement20	1	1	0	0	0	1	1	1	0	0	0	0	0	1	1
70	GametheoreticOptimization2	1	1	0	0	0	1	1	1	0	0	0	0	0	1	1
71	timalDesignRenewable2024	1	1	0	0	0	1	1	1	0	0	0	0	0	1	1
85	ToesMapping2018	1	1	0	0	1	1	1	1	1	0	0	1	1	0	1
86	rePathwaysMainstreaming201	1	1	1	1	1	0	1	1	0	0	0	0	0	0	1
89	keholderDemandsRegulatory2	0	1	0	0	1	1	1	1	1	0	0	1	1	0	1
96	DevelopmentProspectsEnergy	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1
111	natLocalSmart2021	1	1	1	0	1	0	1	1	0	1	1	1	1	1	1
113	gningSuccessfulEnergy2022	1	1	1	0	1	1	1	1	0	1	1	0	1	1	1
141	blishingValueCommunity2021	1	1	0	0	0	0	0	1	0	0	0	0	0	1	1
142	tiFlexibilityProvisionsLocal202	1	1	1	1	1	0	1	1	0	0	0	0	0	1	1
153	esponsiveFLEXibilitySmart202	1	1	1	1	1	0	1	1	0	0	1	0	0	1	1
155	nergyStorageMulti2020	1	1	0	1	1	0	0	1	0	0	1	0	0	0	1
156	InnovativePowersharingModel	1	1	1	1	1	0	1	1	0	0	1	1	0	0	1
157	nergiesPowertoHeatPowertoG	1	1	0	1	1	0	1	1	0	0	1	0	0	0	1
158	AutomatedEnergySharing2022	1	1	0	0	1	0	1	1	1	0	0	0	0	0	1
160	noeconomicAssessmentUnive	1	1	0	0	1	0	0	1	0	0	1	1	1	0	1
164	elizRobustOptimalCoordinatic	1	1	0	0	1	0	0	1	0	0	1	0	0	0	1
175	ockingResponsiveFlexibility20	1	1	0	0	0	0	1	1	0	0	1	0	0	0	1

- E.g. I want to read about papers that study **batteries** at **district level** with **prosumer** perspective
- E.g. I want to check if the data used in this paper is **open data** or not
- E.g. I want to know if the study is pure **technic** paper or **social governmental** study paper

Analysis: publication landscape



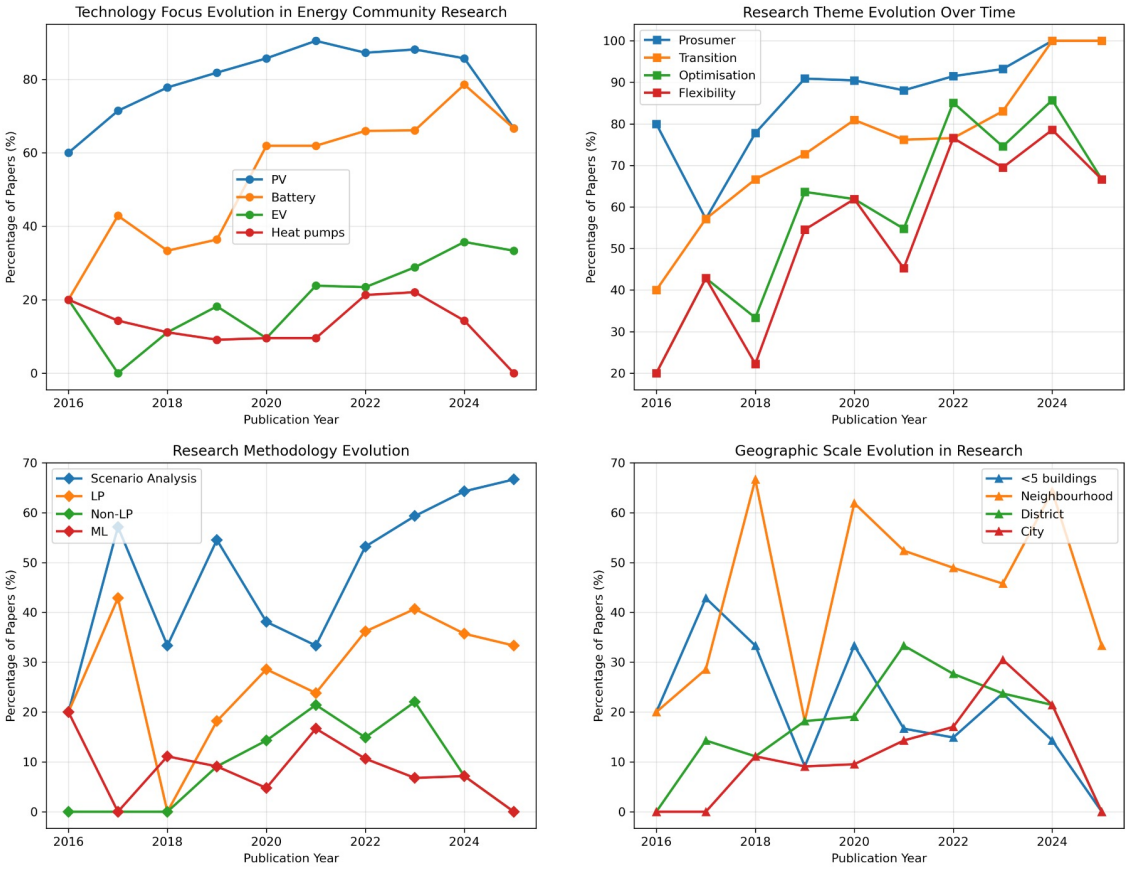
Sharp acceleration post-2019

Peak in 2023 with 59 papers — driven by policy shifts and funding for decentralised energy

2025 partial year (until May)

The field is still young but expanding rapidly

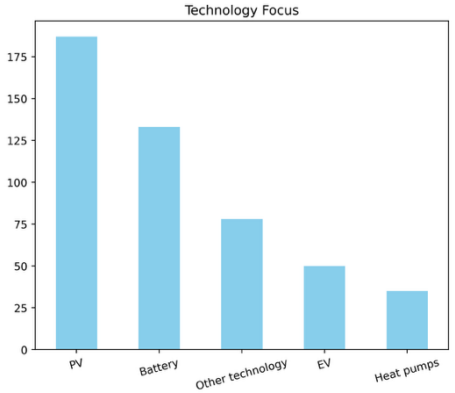
Analysis: publication landscape

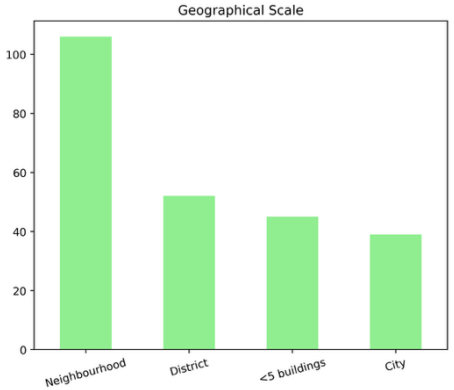


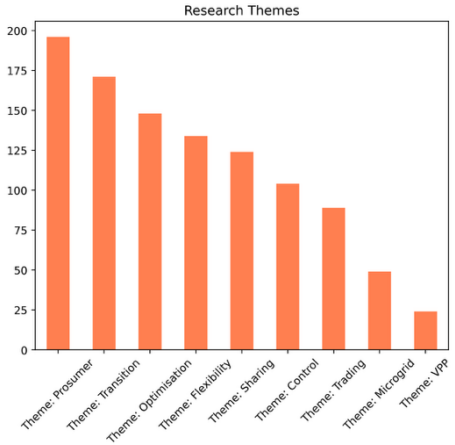
- Technical dominance: PV & Battery are the most common focus, while integrated heat-electricity-mobility solutions are rare
- Research theme: Prosumer & transition studies
- Research Method: Scenario & simulation
- Geographical scale: Neighbourhood

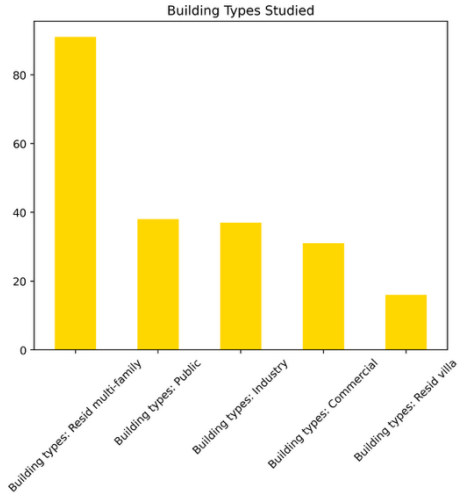
RI. SE

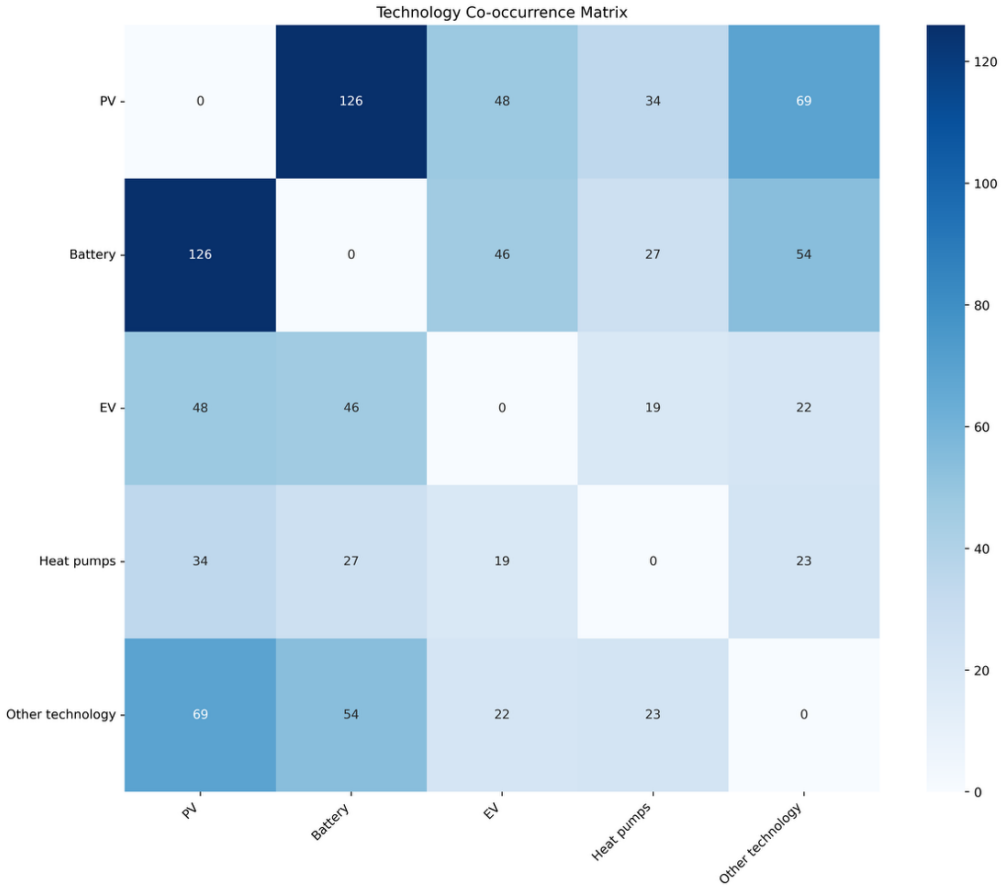
Analysis: publication landscape



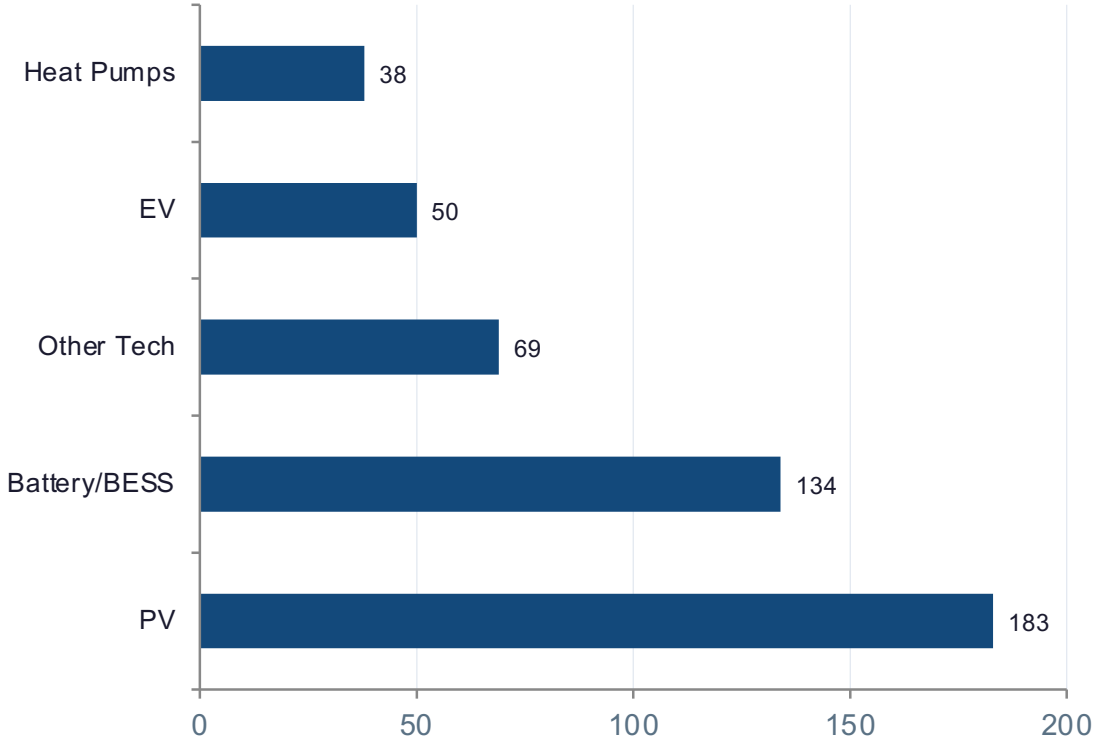








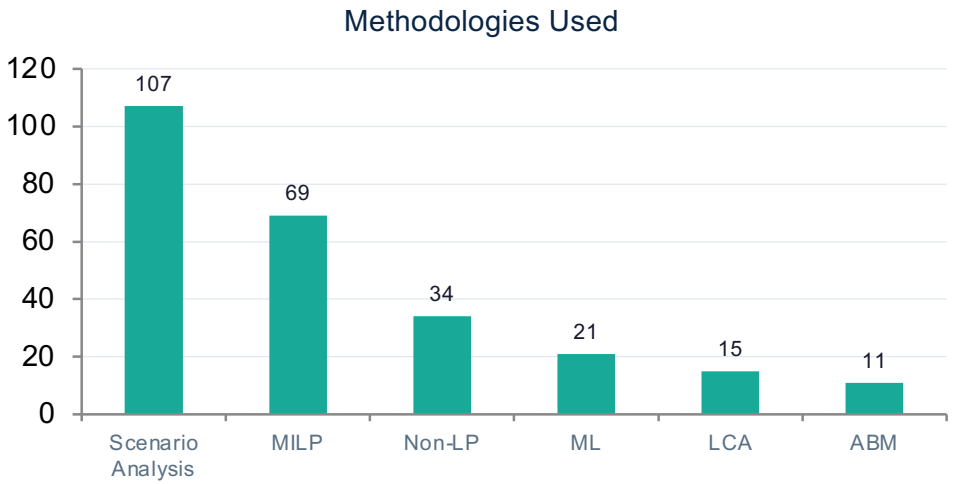
Technology Focus: PV Dominates, BESS Rising Fast

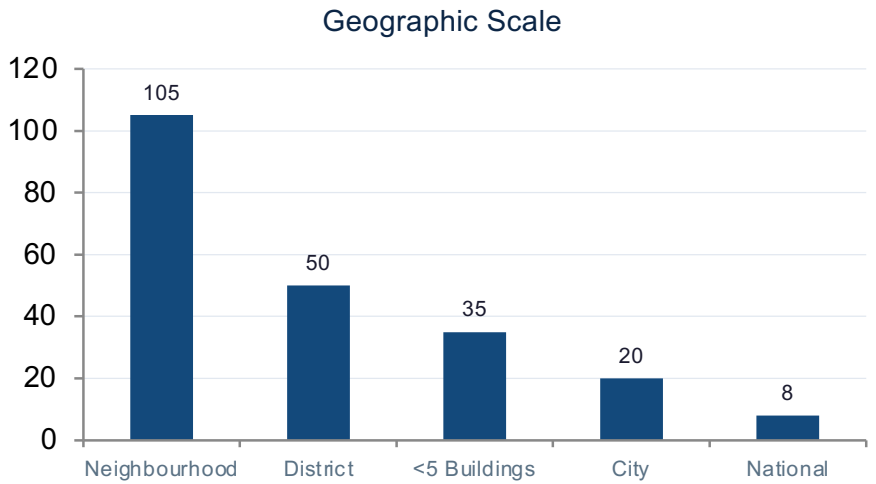


PV + Battery is the most common pairing (126 co-occurrences)

EVs still underexplored — often modelled as loads, not as controllable flexibility assets

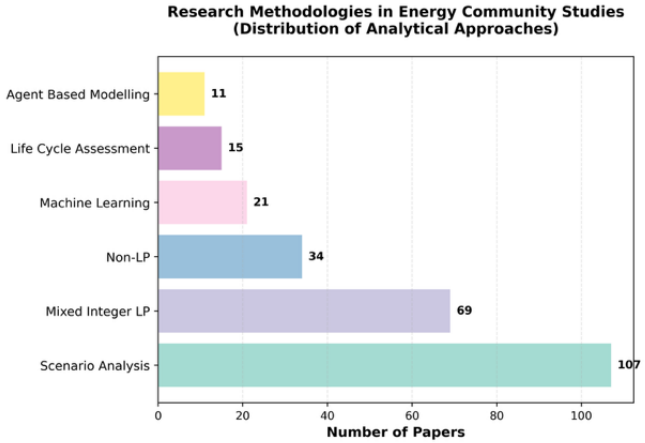
Research Landscape: Methods & Scales

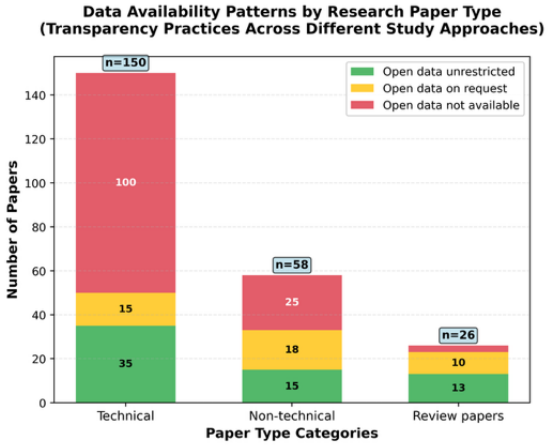


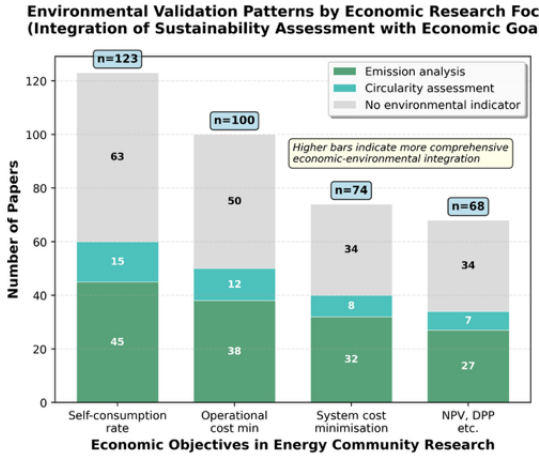


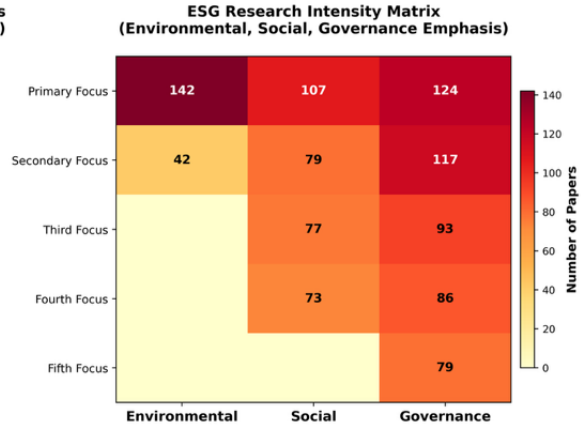
Scenario analysis + MILP dominate · Empirical validation is scarce · Only 23% of technical papers share open data (see next slide)

Analysis: publication landscape

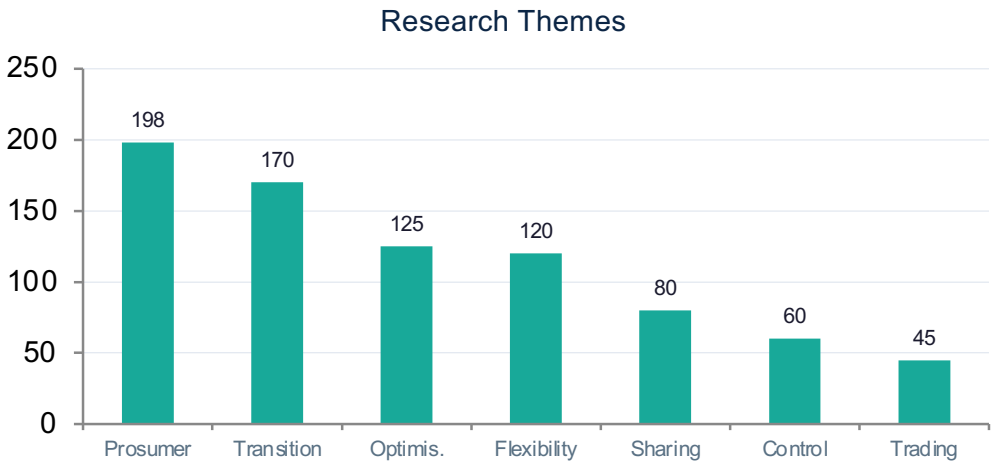








Research Themes & ESG Balance

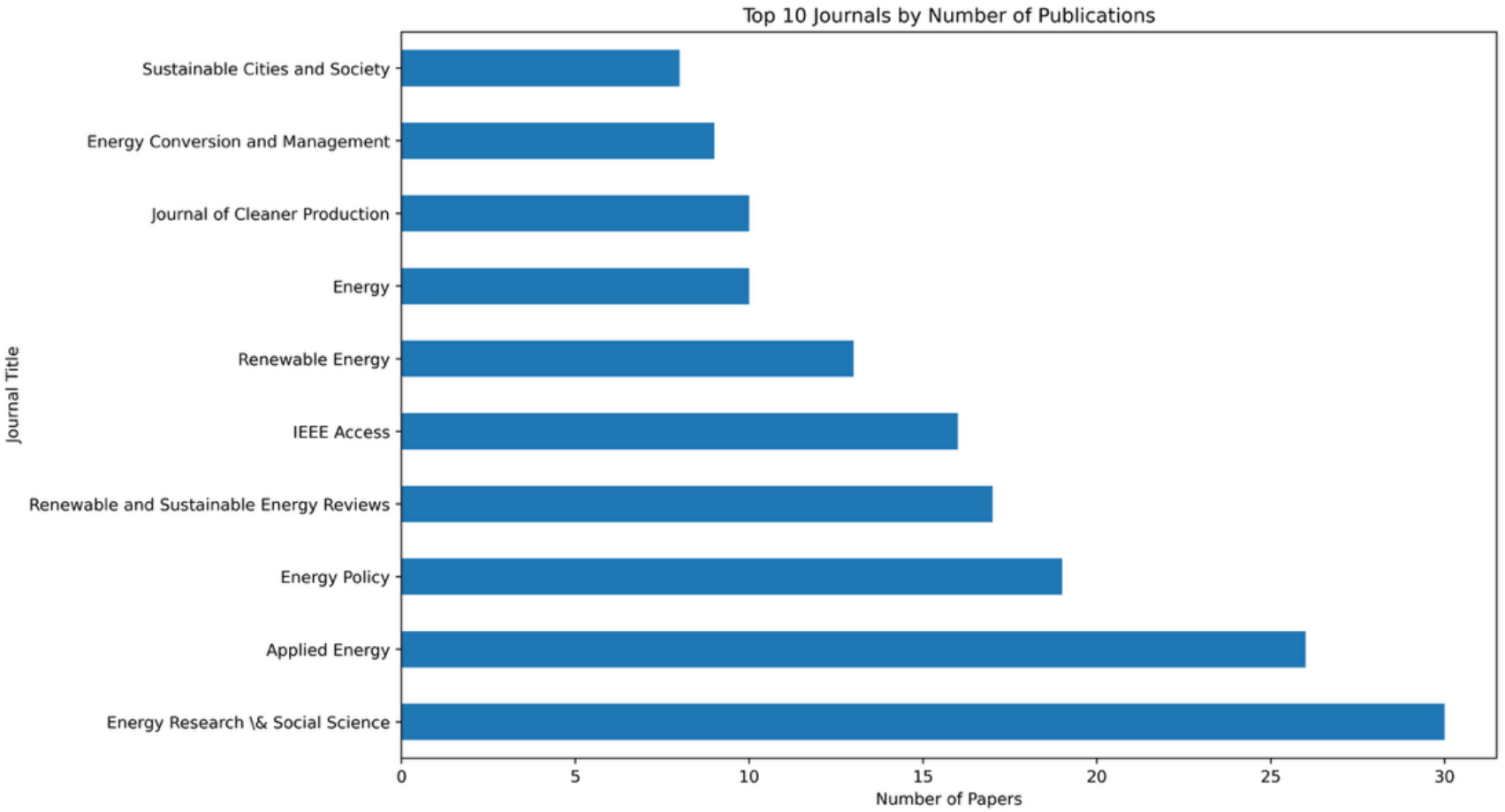


ESG Priorities (# as primary focus)

Social & Governance Detail

Community engagement: 107
Market issues: 124
User behaviour: 79
Business models: 117
Social acceptance: 77
Policy: 93
Energy justice: 73
Democracy: 79

Analysis: publication landscape



Semantic Clustering: Six Research Orientations

C1 (67) Tech & Operations

Battery, grid, storage, demand, renewable. System design and optimization.

C2 (60) Policy & Social Transition

Business, policy, social, transition. Governance, collective action.

C3 (9) Cost-Benefit & Markets

Cost, market, generation, storage. Techno-economic evaluation.

C4 (29) Building-Level Sharing

Building, sharing, storage, economic. Peer-to-peer models.

C5 (35) Consumer Value & Equity

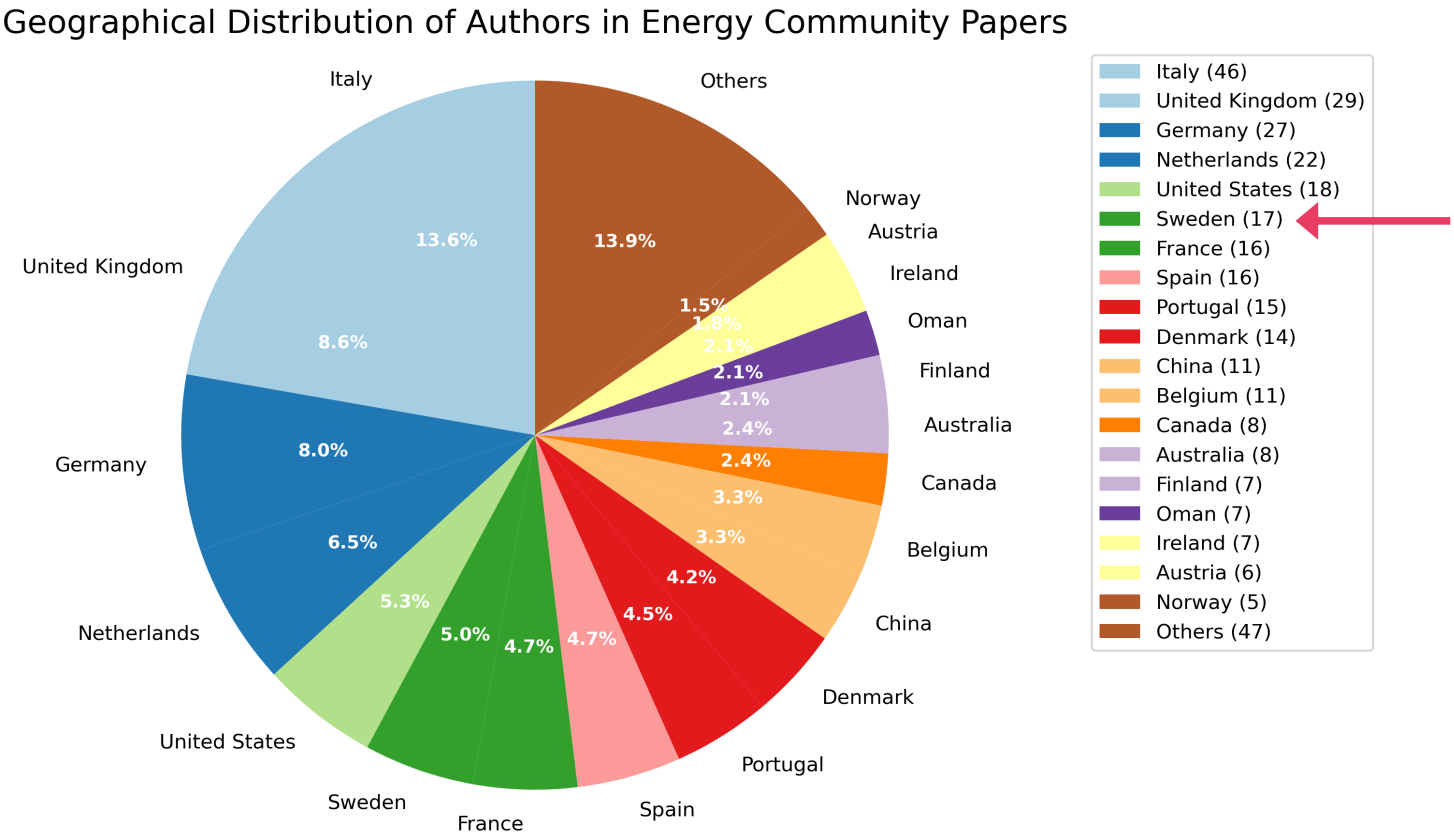
Consumer, value, solar, market, cost. Fairness of cost-sharing.

C6 (10) Empirical Case Studies

Case, member, operation, policy. Practical validation — still rare.

RI.SE

Analysis: publication landscape



Opportunities for Sweden

Co-optimise BESS + EV

Combine community batteries with smart charging and V2B/V2G for peak shaving, arbitrage, and ancillary services

Evidence-Rich Pilots

Shift from simulations to monitored demonstrators with open data, standardised KPIs, and multi-year reporting

Exploit Sector Coupling

Leverage district heating + building stock for PV+BESS+heat pump integration; absorb surplus at negative prices

Fairness by Design

Embed governance, cost/benefit sharing, and protections for tenants and low-income households from the start

Who can use the results?

Policymakers

Create regulatory sandboxes for PV-BESS-EV assets; design dynamic tariffs that reward flexibility; mandate standardised KPI reporting; fund sector-coupling pilots

Researchers

Run longitudinal field studies on integrated systems; benchmark control strategies on shared open datasets; evaluate governance models experimentally; study transferability across contexts

Industry & Developers

Deploy co-optimisation controls for PV/BESS/EV; invest in open data interfaces and KPI dashboards; design business models around value-stacking; target mixed-use communities

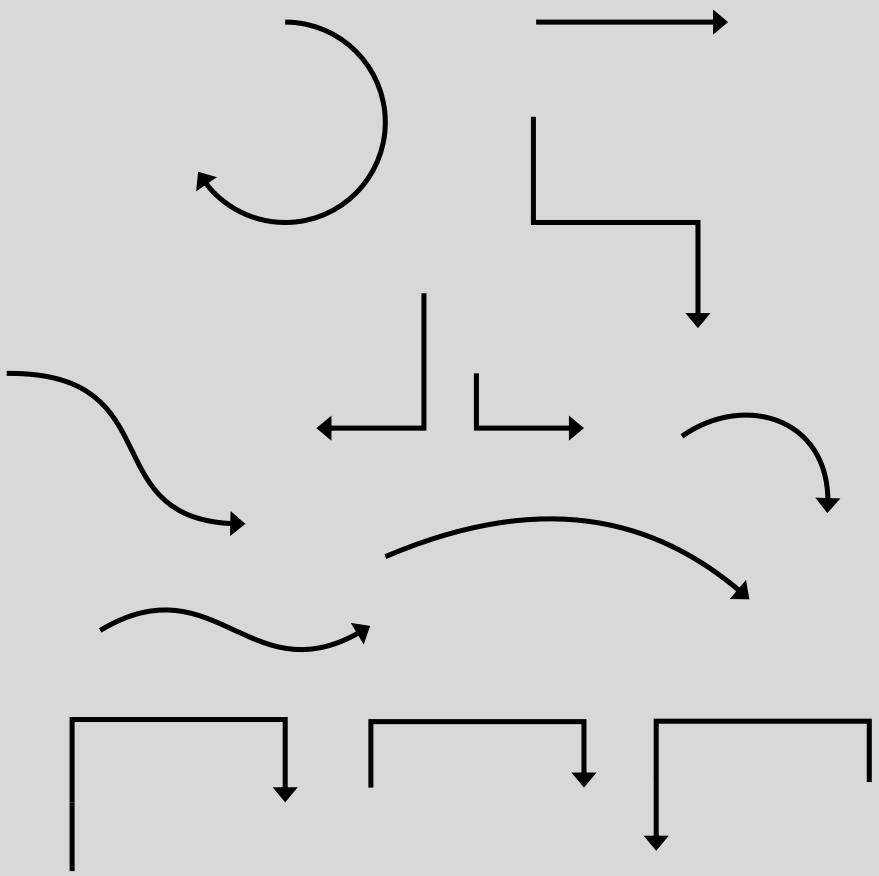
Energy Community Members

Understand benefits and trade-offs of participation; advocate for fair cost-sharing rules; engage in democratic governance; demand transparency on performance and costs

Discussion & Final takeaway

- Limitations of the study:
  The review includes only English-language peer-reviewed literature. Grey literature was excluded. Very recent developments may not yet be fully reflected. And not all results from non-Swedish contexts will transfer directly to Sweden.
- The main takeaway is that energy communities are moving from a promising concept toward a practical transition tool, but the field is still dominated by modelling and partial system views.
- The next step is not more of the same. The next step is integrated, real-world, evidence-rich implementation that combines technology, economics, governance, and fairness.
- For Sweden, the opportunity is to use its strengths in policy, PV/EV integration, and social acceptance to lead the shift from theoretical potential to practical, scalable, and equitable energy communities.

RI.
SE



Chang Su, PhD

chang.su@mdu.se

Biträdande lektor

Institutionen för teknikvetenskap

Mälardalens universitet