

Solar for Tenants: Exploring Collective Self-Consumption in Multi-Family Housing

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Abstract— Collective self-consumption (CSC) in multi-family buildings presents a promising strategy to expand access to photovoltaic (PV) electricity in urban settings and is actively supported by recent EU directives. However, national implementations remain highly diverse highlighting the need for a systematic understanding of CSC system designs. Through a structured literature review, 41 peer-reviewed studies were analyzed to identify and classify six recurring CSC archetypes based on four key design dimensions: participation scale, consumption model, production model, and point of installation. Four primary archetypes are discussed in detail, highlighting their implications for PV-sharing system design and stakeholder inclusion. This synthesis provides a framework for comparing CSC models across different policy environments, highlighting trade-offs between centralized coordination and individual autonomy, and informing policy design for inclusive renewable energy adoption.

Index Terms— collective self-consumption, energy sharing, multi-family building, photovoltaic, tenants.

I. INTRODUCTION

The European Union’s renewable energy transition aims to address climate change while fostering inclusivity and social equity [1]. However, tenants in multi-family buildings – comprising nearly half of the EU population [2] – are often excluded from direct access to renewable energy sources. Photovoltaic (PV) systems, in particular, have become increasingly cost-effective and modular, making them well-suited for distributed generation [3]. Yet, they remain more readily available to single-family homeowners [2], leaving tenants behind due to structural barriers such as split incentives [2], [4]. The split incentive issue arises because landlords bear the upfront investment costs of retrofits, while tenants primarily benefit from reduced energy bills [5], [6], creating a financial misalignment that discourages implementation and increases tenants’ susceptibility to rising energy prices and energy poverty [4].

Collective self-consumption (CSC) models offer a promising pathway to address this exclusion by enabling residents in multi-family buildings to jointly consume locally generated PV electricity [7], [8]. CSC improves system economics by aggregating diverse household load profiles, increasing self-consumption rates, and reducing grid

dependency [9], [10], [11]. Recent EU directives support such models [12], [13], promoting flexible ownership structures – ranging from individual investors to third-party operators [14], [15] – and enabling tenants to benefit from clean electricity without owning rooftop systems [6].

Despite growing policy interest, CSC adoption in multi-family contexts remains fragmented due to diverse legal interpretations [16], high transaction costs, and coordination challenges [17]. Moreover, while case-specific studies exist, systematic comparative analyses of CSC design typologies remain scarce. As Minuto and Lanzini [18] note, the “lack of a deep and detailed investigation on the sharing mechanism in this energy policy framework results in a significant scientific literature gap.”

To provide an international overview on CSC models in multi-family buildings, this study systematically reviews current research on such concepts in scientific literature using the structured approach proposed by Webster and Watson [19]. Our analysis focuses on common system design (archetypes), according to four dimensions – participation scale, consumption model, production model, and point of installation. The resulting archetypes serve as a foundation for further research on stakeholder dynamics and PV-sharing mechanisms. By classifying recurring system architectures, this study seeks to answer the following research question:

What are the common archetypes of CSC in multi-family buildings?

The resulting archetypes enable a structured comparison of CSC models across diverse legal and market contexts, clarifying where existing schemes align or diverge in practice. By highlighting recurring design choices and stakeholder configurations, the study offers policymakers, multi-family building owners, and energy providers a clearer basis for adapting CSC to local conditions. In doing so, it contributes not only to theoretical discourse on decentralized energy systems but also to practical decision-making aimed at expanding renewable energy adoption in multi-family environments.

II. RESEARCH BACKGROUND

A. *Collective Self-Consumption: Spatial Scope*

Participation scale plays a crucial role in shaping CSC models in multi-family buildings. According to EU Directives 2018/2001 [12] and 2019/944 [13], households can collaborate in different spatial scopes to jointly produce, store, and distribute renewable energy, whether through a single PV system shared within one building or broader neighborhood models. The legislative framework distinguishes “jointly acting renewable self-consumers” (multiple units in a building that share PV output), renewable energy communities (spanning multiple buildings and often involving public institutions and businesses), and citizen energy communities (which can include more diverse energy sources and operate across wider areas). Despite these formal distinctions, all three are frequently referred to as variants of CSC, given their common aim of creating shared access to renewable energy.

Beyond these legal definitions, recent research has emphasized the difference between place-based and non-place-based energy communities [20]. Place-based models are embedded in shared infrastructure and community identity, aligning closely with CSC confined to one or several adjacent buildings. In contrast, non-place-based models make use of digital platforms and contractual governance to span dispersed geographies – enabling broader participation but potentially increasing governance complexity and reducing local consumption benefits. For instance, Spain allows a 2 km proximity requirement between the generating unit and the consumers [21]. This underscores the potential for sourcing PV electricity from locations beyond the immediate premises, thereby broadening the range of feasible installation and ownership options.

B. *Stakeholder Complexity in Multi-Family Buildings*

These spatial distinctions not only determine the technical and legal feasibility of CSC setups but also shape the complexity and composition of stakeholder groups involved in implementation and operation. Unlike single-family homes, where a single owner typically decides on solar installations, multi-family buildings can involve multiple owners, cooperative housing associations, corporate investors, and tenants [22]. In the CSC landscape, four overarching roles often shape the dynamics of PV sharing: consumers, producers, prosumers, and managers.

Consumers – typically tenants – use the electricity generated by the PV system. Prosumers – oftentimes owner-occupiers – blend consumer and producer interests due to their dual status as both residents and investors [23]. Producers – oftentimes building owners, or owners’ associations – supply and often own the PV system, make decisions on upgrades, and manage the upfront costs [24]. Managers are responsible for coordinating operational tasks such as energy allocation, metering, billing, and grid interaction. This management function can be performed by the building owners who funded the PV system, by a third-party investor [25], or by an external energy services entity [6], [26]. Depending on the specific ownership and contractual arrangements, certain operational tasks – such as minor maintenance, metering, or billing – may

be shared among owning entity and external service provider [27]. Where PV systems serve multiple users or cross parcel boundaries, the energy transaction becomes a complex process involving transmission and distribution system operators, retailers, and prosumers – each with distinct responsibilities and regulatory requirements [18].

Beyond the distinct stakeholder roles, the structure of PV-sharing arrangements fundamentally shapes how these actors interact. As outlined in [18], models can vary considerably depending on how electricity is allocated – for instance, through virtual metering, where multiple PV systems are treated as a single point of delivery, or via peer-to-peer trading, where electricity is exchanged directly between individuals. The addition of shareable assets such as energy storage systems [27] further increases complexity by introducing new degrees of flexibility and decision-making, especially around timing and distribution of consumption.

These system design choices are not purely technical decisions – they shape how responsibilities, benefits, and control are distributed among stakeholders, influencing project feasibility and long-term governance dynamics. Yet, while previous reviews have predominantly focused on the concerns of producers and managers [4], [28] – such as investment risks, regulatory incentives, or tenant engagement – less emphasis has been placed on how these system design decisions themselves enable or constrain stakeholder roles. A more holistic understanding of PV system architectures is therefore essential for assessing the broader socio-technical dynamics, including collaboration, regulatory compliance, and economic viability. This aligns with recent calls in the literature to move beyond isolated technical descriptions toward more generalizable system classifications that can guide policy and design decisions [7], [18], [29].

III. METHODOLOGY

To study the aforementioned complexities, we employ a structured literature review, grounded in the principles outlined by Webster and Watson [19] to find common CSC concepts for multi-family settings investigated in scientific literature. The review process ensures systematic identification and selection of scholarly contributions, providing a robust foundation for exploring the intersections of PV sharing and multi-tenant residential settings.

The search process utilized a rigorously constructed search string to capture a broad yet focused range of literature addressing key themes, including direct PV sharing, energy communities, and remote energy sharing, with a specific focus on multi-family buildings and tenant participation. Therefore, the search string incorporated three concepts, “collective self-consumption”, “solar energy”, and “multi-family buildings” (see *Appendix 1 Table I*), linked by AND-operators. This search string was applied across multiple academic databases, i.e. Scopus, Web of Science, Taylor and Francis, ACM, AIS eLibrary, EBSCOhost, ProQuest, Sage Journals, emerald insight, Science Direct, and IEEE Xplore, ensuring comprehensive coverage of relevant research.

To refine the search results, exclusion and inclusion criteria were defined. The exclusion criteria for our search are

focused on a meta level: non-english (EX1), inaccessible (EX2), false positives (EX3), non-peer-reviewed literature (EX4), overview paper (EX5). The inclusion criteria applied in our search comprise of content-related aspects: articles discussing CSC concepts in the context of multi-family buildings (IN1), articles that include discussions of PV system design and stakeholder involvement in CSC (IN2).

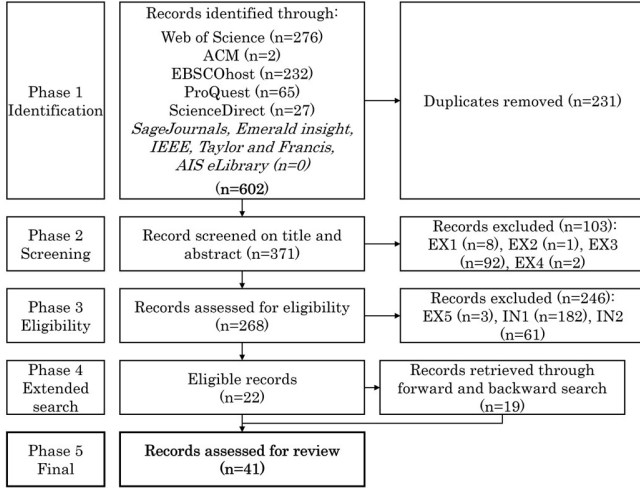


Figure 1 – The systematic literature review process, following Webster and Watson [19], illustrated as PRISMA flowchart [29].

The initial search yielded 602 articles. These were filtered through a multi-phase process, depicted in *Figure 1*: In a first phase duplicates were removed. Phase 2 included the screening of titles and abstracts with EX1-EX4 to align with the aimed research objective and quality. In phase 3, eligibility was evaluated through full-text review. Additional sources were identified through backward and forward search (phase 4), examining citations within the selected literature to uncover further contributions pertinent to the study's focus.

The final dataset of 41 articles was systematically analyzed using a concept matrix designed to capture essential characteristics of system design for CSC in multi-family contexts. This matrix focuses on how PV systems are physically configured and operated – decisions that fundamentally shape stakeholder involvement from the outset. The full table is provided in *Appendix B Table II*. Four principal dimensions guided the analysis:

- **Participation Scale (Unit [U], Building [B], Neighborhood [N]):** This dimension indicates whether the self-consumption arrangement is organized at the level of a single apartment or unit, encompasses an entire building, or extends across multiple buildings in a neighborhood, including shops and public facilities. Where studies addressed multiple spatial levels (e.g., unit and building), we assigned them to the higher level of participation if the system characteristics were consistent to identify broader design patterns across contexts.
- **Consumption (Individual [I], Aggregated [A]):** “Individual” consumption is an accounting-based model comparing each household’s metered usage with total PV output, allowing occupants to adapt consumption (e.g.,

run appliances during peak solar hours) to increase their effective share of green energy on paper. By contrast, “Aggregated” consumption pools all participants’ demand, simplifying billing but limiting an occupant’s ability to tailor usage for a higher solar share.

- **Production (Individual [I], Joint [J]):** “Individual production” designates scenarios in which each unit has its own dedicated PV system, thus creating a decentralized model. “Joint production” refers to collectively owned or operated PV arrays, where electricity is generated under a shared system and subsequently distributed among participants.
- **Point of Installation (Rooftop [R], Balcony [B], Facade [F], External [E]):** This dimension specifies where the PV panels are installed. Rooftop, balcony, and facade installations take advantage of a building’s existing envelope, while “External” covers any off-site or ground-mounted systems located elsewhere within or near the property.

IV. RESULTS

A. Archetypes for Collective Self-Consumption in Multi-Family Buildings

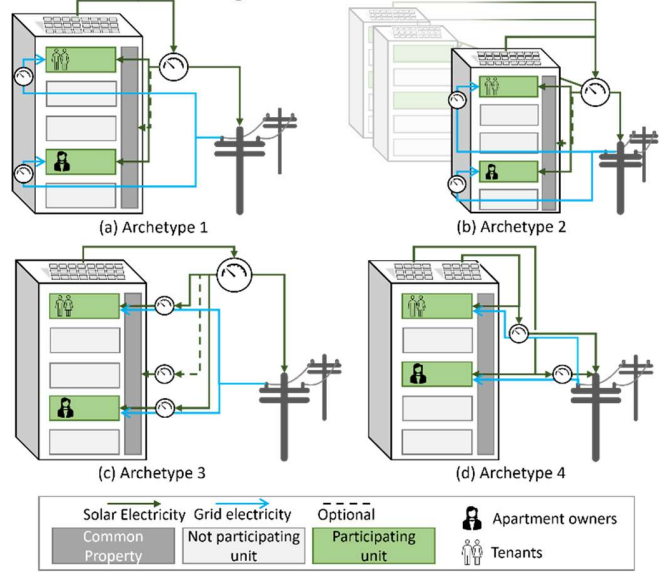


Figure 2 – CSC archetypes 1 to 4

Based on the concept matrix introduced in *Section III* and detailed in *Appendix B Table II*, we synthesized six distinct CSC archetypes by systematically categorizing system designs discussed in the reviewed literature. The four most frequently observed archetypes are described below, as depicted in *Figure 2*. The remaining two – joint production with individual consumption at a neighborhood scale (archetype 5) and individual production and consumption at the neighborhood scale (archetype 6) – are outlined in *Appendix B Figure 4*, as their recurrence was limited to a single study each. The meter points shown represent virtual balancing mechanisms used for billing and allocation – not physical metering infrastructure.

Overall, our analysis of publication trends reveals that CSC in multi-family housing gained prominence following its formal EU definition in 2018 and 2019, as evidenced by the publication peak in 2019 and sustained research interest thereafter (see *Appendix A Figure 3*).

1) *Joint Production with Aggregated Consumption at the Building Scale (Archetype 1)*

In this archetype, a shared PV system, owned and operated by a collective of residents [30], [31], [32], owners' association [33], building owner [34], or external service provider [35], [36], supplies electricity to offset the aggregated energy demand of the participating units (i.e., tenants, apartment owners) in the building, including common property (e.g., [37], [24], [38]). In this arrangement, individual units lack direct control over how PV electricity is allocated to their bills, as distribution for the entire building is centrally managed by the owners' association [39] or an external service provider [40]. Most studies focus on rooftop installations [41], though facade-mounted panels also appear [42]. Moreover, this archetype has been further studied with an optional central battery [39], [43] [44]. Roberts et al. [26] comes to the conclusion, that despite high initial costs, a central battery has clear financial benefits by increasing the flexibility of load matching.

In Australia, this approach corresponds to an "embedded network", where the owners' association or a third party serves as the embedded network operator and sells both PV and grid electricity to residents [45]. Similar concepts can be found in Germany. Under the tenant electricity (Mieterstrom) model, the property owner or a third party owns and operates the PV system on the building's rooftop and serves as the tenants' sole electricity provider. In return, tenants pay a fixed tariff, which is usually lower than the grid price [5], [46].

2) *Joint Production with Aggregated Consumption at the Neighborhood Scale (Archetype 2)*

This archetype extends beyond a single building, integrating multiple structures into a shared PV system. Electricity is pooled and allocated collectively, improving self-sufficiency at a district level. As in Archetype 1, the PV system is either owned by a collective of residents [47], owners' association [45], or an external service provider [21]. The electricity demand of individual units and common areas is aggregated across all buildings, while an external service provider handles the financial allocation of PV and grid electricity to each participant [45]. Rooftop and facade-mounted PV systems are prevalent, and battery storage may be implemented either per building or centrally for the community [42], [48], [49]. On both levels, battery storage allows more PV capacity to be efficient, but the financial benefits are insignificant for individual customers [42].

Archetype examples include "consumer stock ownership plans" in Poland, the Czech Republic, and Italy, where a trust limited liability company owns the PV system. Tenants pay monthly fees in exchange for electricity and receive capital participation proportional to their consumption [50].

3) *Joint Production with Individual Consumption at the Building Scale (Archetype 3)*

This archetype involves a single, shared PV system installed on a multi-family building, where the generated electricity is then allocated and consumed by individual residential units and common property. This arrangement employs a metering system to track and distribute the PV electricity among different units. By adjusting their consumption patterns, individual units can increase their accounted share of PV electricity. The PV system is owned by a collective of residents [7], [51], owners' association [23], or an external service provider [52] which sell the PV generation to the residents under a power purchase agreement [45], [53]. The system distribution typically resides on the building rooftop [23], [54] and its efficiency can be improved by the integration of battery storage in each apartment, centralized for the entire building, or by integrating EVs to the storing strategy [7], [52], [55]. Compared to archetype 1, Domenig et al. [2] shows that in some cases, a building level battery can increase revenue up to 59%.

In Australia, the "shared behind-the-meter" model exemplifies this approach: although the owners' association owns the PV system, individual residents can adjust their usage to increase the share of PV electricity accounted to them [53].

4) *Individual Production and Consumption at the Building Scale (Archetype 4)*

In this archetype, individual apartments and common property within a multi-family building have their own, independent PV systems. Each system serves only the unit it is attached to, making it a decentralized model. The PV system is either owned by individual residents [6] or by an owners' association [45]. If the owners' association owns the PV system, the units can either lease their share of the system from them or have its costs included in their rent [6]. The units decide how much energy of their PV system they consume or feed into the grid. Furthermore, this model exists with the possibility of units trading energy among each other (dynamic) or without it (static) [56]. As in Archetype 3, the PV system is located predominantly on the roof [26], [57]. Battery storage is considered both at unit level and building level [57].

In Australia, this arrangement corresponds to the "individual behind-the-meter" model, where each apartment maintains a private PV system and deals independently with grid imports or exports [45]. Financial arrangements vary: residents may purchase, lease, or include PV system costs in rent. Decision authority is often decentralized, requiring unit-level agreements for changes or upgrades.

B. *Archetype Divergence*

Across the reviewed literature, treating a building as an aggregated load is nearly twice as common as focusing on individual units. Regardless of the self-consumption rate, aggregated approaches consistently yield lower overall electricity costs for residents, in part because a shared PV system can reduce installation expenses and reliably meet aggregated demand [45]. By contrast, individually operated PV systems are more complex to implement due to permission and liability issues, yet they allow residents to capture direct

financial or tax benefits without a third-party intermediary [6], [45].

Archetypes 1 and 2 require a control entity to manage the allocation of PV-generated electricity alongside grid electricity. This entity (e.g., an external service provider [33], [40]) is often assumed by the system’s owner but may be contracted out [52]. Archetype 3 decentralizes allocation, with individual units managing their PV output by optimizing overall energy use [7]. Archetype 4 involves no central allocation if each apartment has its own PV system, although a “dynamic model” can enable trading between units [56]. In practice, adding more stakeholders to manage allocation can improve the system’s efficiency but tends to reduce individual financial gains as each stakeholder takes a portion [6].

C. *Archetype Consensus*

Despite notable differences, certain themes run through all four archetypes. Most research emphasizes electricity use for household appliances, yet some also consider heating and, less frequently, cooling loads [2], [37], [56], [58]. This reflects the broader shift toward electrified heat pumps and away from fossil-based heating. Additionally, these models do not depend on whether occupants are tenants or owner-occupiers, and none require residents to own the PV system. In Archetypes 1 through 3, a single building owner, owners’ association, or third party typically holds the PV installation [23], [24], whereas in Archetype 4, the PV can be leased to residents [56] or be resident-owned. Moreover, participation is voluntary in every archetype, so not all residents must opt in. Finally, all approaches still rely on grid electricity to cover demand that exceeds PV generation, and even with battery storage, self-sufficiency remains limited – ranging from roughly 20% to 40% in most studies, and peaking at 68% [7], [48], [58], [59] – largely due to the chosen size of the PV systems.

V. DISCUSSION

A. *Principal Findings*

This review identifies four predominant CSC archetypes for multi-family buildings – ranging from fully centralized PV systems at the neighborhood level (archetype 2) to decentralized, unit-level installations (archetype 4) – and notes two additional archetypes that appear less frequently. Across these models, maximizing self-consumption, especially from roof-top mounted PV, consistently emerges as a core priority for reducing dependence on the electricity grid and lowering overall costs. The growing electrification of heating and mobility further elevates the importance of storage integration and load coordination in CSC systems, particularly as households adopt heat pumps and EVs.

Three themes stand out. First, effective stakeholder collaboration is critical, especially in shared or neighborhood systems. Second, aggregating a building’s load can reduce overall electricity costs but may diminish incentives for individual energy-saving measures. Third, whether PV ownership is collective or individual determines how costs, liabilities, and benefits are shared, creating a tension between collective efficiency and personal autonomy.

B. *Contributions*

By examining the key dimensions through which CSC can be categorized, this study highlights the unique operational and economic complexities of multi-family building contexts. These dimensions serve as a comparative tool, allowing researchers, policymakers, and building stakeholders to evaluate how various CSC configurations align with diverse ownership structures, regulatory settings, and objectives. This overview not only clarifies recurring design patterns but also lays a foundation for deeper inquiry into stakeholder relationships and governance models, which can be more meaningfully explored once the underlying system designs are understood.

C. *Limitations*

The prominence of specific archetypes in this review reflects the focus of scientific literature rather than any inherent technical or economic superiority. Many studies rely on simulations of buildings that vary in size, PV capacity, and analysis period, limiting direct comparability of their findings. Moreover, certain models are investigated under forward-looking or hypothetical policy frameworks, meaning their real-world feasibility is not always assured under present regulations. In some cases, researchers specifically propose or test new policies as part of their analytical scope, indicating that these studies are as much about informing policy evolution as they are about evaluating existing conditions.

D. *Future Work*

Using the archetypes identified in this study, future research should delve into how day-to-day management tasks – such as billing, metering, and dispute resolution – function in practice, especially in newer scenarios like balcony PV systems or external PV installations. Tariff structures warrant particular attention in light of the forthcoming EU Directive 2024/1711, which introduces free supplier choice and allows multiple contracts [60], raising questions about parallel tariffs and how incentives are balanced among all stakeholders. Beyond regulatory frameworks, another vital research area involves assessing the effectiveness of different incentive strategies. Countries frequently employ investment-based or operational mechanisms (e.g., reduced grid fees) to foster CSC adoption [61]. Determining which incentives align best with each archetype will be key to shaping policies that enable sustainable, equitable CSC in multi-family contexts.

E. *Conclusion*

This study confirms the value of CSC for expanding renewable energy access in multi-family contexts – but its real-world viability depends on matching system design with governance capacity and stakeholder incentives. By classifying recurring archetypes, this review provides a foundation for tailoring CSC implementation to diverse legal, spatial, and ownership environments. As regulatory frameworks evolve, translating these models into practice will be crucial for achieving inclusive, efficient, and resilient urban energy transitions.

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APPENDIX

A. Structured Literature Review: Search

Table I – Search terms employed for each concept.

Collective self-consumption	Solar energy	Multi-family building
(prosum* OR self-consum* OR collective self-consum* OR CSC OR peer-to-peer OR P2P OR local energy market* OR energy communit* OR microgrid* OR collective renewable energ* OR power purchase agreement* OR PPA*)	(solar OR photovoltaic* OR PV*)	(tenant* OR apartment* OR flat* OR condo* OR dwelling* OR multi-family OR multi-tenancy OR condominium* OR multi-story)

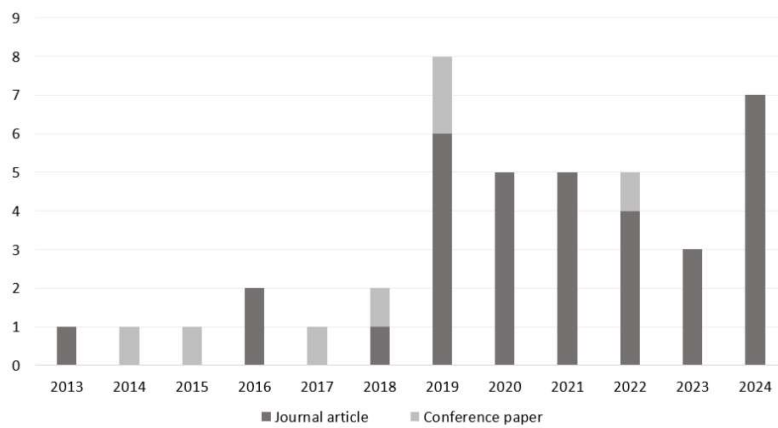


Figure 3 – Distribution of journal and conference papers identified through the structured literature search, organized by publication year.

B. Structured Literature Review: Results

Table II – Comprehensive concept matrix classifying the CSC system designs identified in each reviewed paper

Reference of papers selected in the Systematic Literature Review	Archetype	Participation scale (Unit [U], Building [B], Neighborhood [N])	Consumption (Individual [I], Aggregated [A])	Production (Individual [I], Joint [J])	Point of installation (Rooftop [R], Balcony [B], Facade [F], External [E])
Roberts et al. (2019)	3	B	I	J	R
	4	U, B	I	I	R
	2	B, N	A	J	R
	3	B	I	J	R
Sagbansua und Kiray (2013)	3	B	I	J	R
Fernandez-Agueera et al. (2021)	2	B, N	A	J	R
Mohammadi et al. (2023)	4	B	I	I	R
		B	I	I	R
Santiago et al. (2024)	1	B	A	J	R
Roberts et al. (2018)	1	B	A	J	R
Reis et al. (2022)	3	B	I	J	R
Parreño-Rodríguez et al. (2023)	2	N	A	J	R
Fina et al. (2018)	3	B	I	J	R
	1	B	J	J	R
Braeuer et al. (2019)	1	B	A	J	R
Roberts et al. (2022)	1	B	A	J	R
Syed et al. (2020)	1	B	A	J	R
Franzoi et al. (2021)	2	B,N	A	J	R
Kichou et al. (2020)	2	N	A	J	R,F
Fina et al. (2021)	2	B,N	A	J	R
Pedrero et al. (2024)	5	B,N	I	J	R
Lowitzsch (2019)	2	B,N	A	J	R
Roberts et al. (2019)	4	U,B	I	I	R
	1	B	A	J	R
Lindberg and Inderberg (2023)	3	U,B	I	J	R
Kühn et al. (2024)	1	B	A	J	R
Sommerfeld und Muyingo (2015)	2	B,N	A	J	R
Minuto et al. (2021)	1	B	A	J	R
Musolino et al. (2014)	1	B	A	J	R
Roberts et al. (2019)	6	N	I	I	R
	1	B	A	J	R
		B	I,A	I,J	R
Garavaso et al. (2021)	3	B	I	J	R
Braeuer et al. (2022)	1	B	A	J	R
Domenig et al. (2024)	3	B	I	J	R
Syed et al. (2020)	1	B	A	J	R
Fina et al. (2019)		B		J	R,B,F
Fina et al. (2019)	1	B	A	J	R,F
	2	N	A	J	R,F
Roberts et al. (2017)	4	B	I	I	R
	3	B	I	J	R
	1	B	A	J	R
Galvin (2024)	3	B	I	J	R
Poshnath et al. (2024)	4	B	I	I	R
Evola and Margani (2016)	1	B	A	J	F
Öhrlund et al. (2020)	1	B	A	J	R
Torre-Rivas et al. (2022)	2	B,N	A	J	R,F
Syed et al. (2020)	1	B	A	J	R
Ramos et al. (2022)	1	B	A	J	R
Fleischhacker et al (2019)	1	B	A	J	R
Kortetmäki et al. (2024)	1	B	A	J	R
Roberts et al. (2016)	1	B	A	J	R

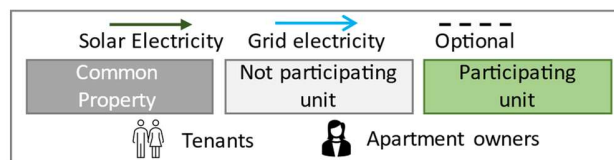
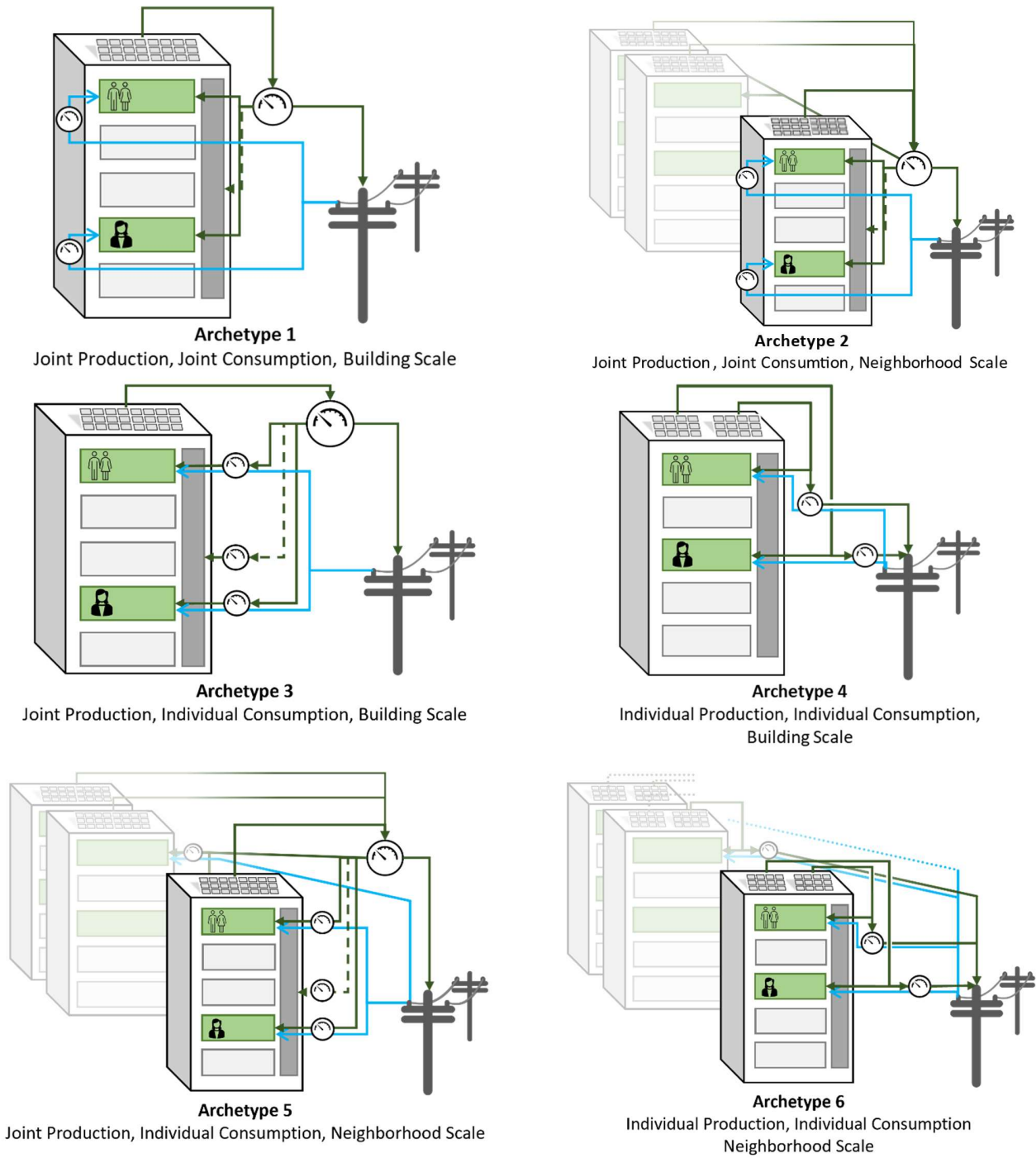


Figure 4 – Overview of the six CSC Archetypes