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Abstract

In addition to self-production and individual disconnection from the national grid, the ongoing decentralization of the electricity market increasingly relies on energy-sharing mechanisms such as energy communities (ECs). This paper presents a parsimonious model that captures key features of the ECs, focusing on how cost and benefit allocation among community members influences net producers' energy contributions and, consequently, the total amount of energy shared within the community. The model accounts for heterogeneity among net producers in terms of residual generation capacity and distinguishes between two net consumer groups with different energy needs. It also incorporates crucial factors such as participation fees, the distribution of economic benefits among market participants, and the impact of sharing congestion externalities. The analysis shows how different sharing rules affect total energy exchange within the community and, in turn, the welfare distribution among participants.

JEL Codes: D16, D25, D70, L50, L94, O42.

Keywords: (Renewable) Energy Communities, Energy Sharing, Market Decentralization, Energy Production and Consumption, Capacity Constraints, Congestion Externalities, Incentive Design.

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Non-Technical Summary

As more households and small businesses install solar panels and generate their own electricity, many are joining forces in what are known as Renewable Energy Communities (RECs). These communities allow members to share locally produced clean energy and are seen as a promising way to make our energy systems more sustainable, resilient, and democratic.

Sharing energy is not as simple as it sounds. While the idea of exchanging extra electricity with neighbors is appealing, there are important questions about how these communities work in practice. Who decides how much energy to share? What rules determine how benefits (like savings or incentives) are divided? And how can we make sure that everyone — not just the biggest producers — has a reason to take part?

Our research develops a simple economic model to better understand these questions. We focus on the behavior of members within a local energy-sharing group, especially those who generate more energy than they consume. We explore how their willingness to share is affected by how the benefits are distributed, how many others are sharing at the same time, and how well demand matches supply across the community.

We find that as more people try to share energy, the system can become congested. This makes each individual's contribution less valuable, and can lead to fewer people wanting to participate. These dynamics are especially important in local systems, where energy sharing depends on coordination among a small group of neighbors.

We also study different ways of splitting the benefits. If the rules only reward those who contribute the most energy, smaller producers may be discouraged. But if benefits are divided equally, larger contributors may withdraw. The challenge is to find rules that balance fairness, efficiency, and participation — ensuring that everyone has a reason to stay involved, while the community remains productive and inclusive.

In short, RECs offer a unique opportunity to reshape how we produce and consume energy at the local level. But for them to succeed, we need to go beyond technology and consider the human and economic factors that drive cooperation. Our study helps identify these trade-offs and provides insights for designing policies that make local energy sharing work better for everyone.

1 Introduction

The European energy landscape is undergoing a profound transformation, driven by the urgent need to mitigate climate change, particularly through the widespread adoption of renewable energy sources. A comprehensive regulatory framework has been established to facilitate the decarbonization of the energy sector, exemplified by the European Commission's Renewable Energy Directive 2018/2001, which supports the European Union (EU)'s ambitious climate targets. This transition has accelerated in recent years, with fossil fuel usage dropping to historic lows, while the share of renewable energy exceeded 40% of total electricity generation for the first time in 2023 (EMBER, 2024). This shift reflects a broader movement away from centralized, fossil-fuel-based energy production toward decentralized, renewable energy generation, empowering consumers to become active *prosumers*, i.e., individuals who both produce and consume their own energy (Gautier et al., 2018).

Against this backdrop, Energy Communities (ECs) have emerged as a key pillar of the energy transition. These are local groups of energy (net) consumers and producers who collaborate to share electricity among themselves, primarily generated from renewable sources, while jointly achieving a series of environmental, economic, and social benefits. ECs are typically autonomous entities with open and voluntary participation, primarily designed to serve the interests of local communities rather than maximize financial profit. By fostering collective energy management, ECs contribute to balancing supply and demand, reducing dependence on the national grid, and promoting social inclusion by enabling broader participation (particularly among vulnerable populations) in the energy transition.

Despite their growing presence across Europe, the distribution of renewable ECs remains highly uneven both between and within countries. This disparity is influenced by differences in governmental support, regulatory frameworks, and local socio-cultural factors. Furthermore, the 'economics' of energy communities remain largely unexplored, with only a handful of theoretical studies attempting to conceptualize market interactions occurring within these emerging forms of decentralization and energy sharing.[1] In particular, Gautier et al. (2025) show that ECs can lower system costs and improve welfare when collective self-consumption is high, identify tariff conditions that align incentives with welfare, and highlight how internal organization shapes benefit distribution without affecting efficiency.

This paper helps bridge this gap by proposing a static theoretical framework designed to capture key market interactions among energy community members in a highly parsimonious way. The model consists of a mass of homogeneous net consumers, each with a unit energy demand (later extended by including a finite number of larger consumers), and a pre-determined number of net producers with pre-installed generation capacity. These producers are heterogeneous in terms of their residual capacity and must decide how much of it to share within the EC and how much to sell to the national grid, considering the remuneration offered by each option. The final objective of our analysis is to determine the amount of energy that will be endogenously exchanged within the community and the underlying surplus distribution among EC members, given (i) the total available supply and the distribution of residual generation capacity among participants; and (ii) the economic incentives set by the community's governance.

In our model, economic incentives are structured around two primary tools that shape net producers' and net consumers' decisions to participate and contribute energy within the EC. The first is the participation fee, which covers the community's fixed operational costs. The second is the allocation of the economic benefit generated by every unit (or kilowatt-hour, kWh) of shared energy. Our analysis is limited to clarifying how the sharing rule within the EC—determining the distribution of costs and benefits among members—affects energy sharing decisions, hence focusing on the intensive margin of participation.

[1] A more substantial body of literature has investigated individual incentives within the broader context of improving the energy system's efficiency, particularly from the perspective of experimental economics. In this regard, see Yeomans and Herberich (2014), Boogen et al. (2022), and Belaïd and Flambard (2023) among others.

A key challenge faced by energy-sharing systems such as ECs is the mismatch between supply and demand during specific time slots, due to the lack of synchronization between production and consumption peaks. In our context, the main concern is not the temporary shortages this imbalance may cause, nor the mechanisms that absorb them, but rather the inefficiencies it generates. Such inefficiencies reduce the net benefit of participating in the EC. To capture this, we adopt a reduced-form approach that is analytically tractable yet rich enough to reflect key features of agents' decision-making processes. Despite its simplicity, this framework produces outcomes that are observationally equivalent with anecdotal and documented experiences of real-world energy communities, avoiding the complexity of dynamic or highly sophisticated models. Central to our framework is a *sharing congestion externality* linked to the size of the community and the total amount of energy traded within its boundaries. This externality affects the shadow price of each unit of energy exchanged and stems from a coordination problem not only between the two sides of the market, but also involving interactions among net producers. This dynamic resembles a form of competition *à la* Cournot, driven by the fact that, at any given point in time, energy demand within the EC is necessarily finite.

Our analysis reveals a fundamental tensions between efficiency, equity, and participation. We demonstrate that ECs can exist only when sharing congestion externalities remain sufficiently limited relative to the economic value of the shared energy. In line with expectations, energy sharing within the EC decreases with grid prices and sharing congestion costs while increasing with perceived economic value. However, a critical trade-off emerges between maximizing total welfare and ensuring equitable distribution among community members, as maximizing community-wide surplus typically requires favoring (i) net producers over consumers; and (ii) large consumers over small ones. Different governance structures —whether municipality-led, producer-led, or consumer-led— may give rise to substantially different outcomes in terms of surplus distribution and community composition, with particularly stark effects on small consumer participation.

The impact of governance choices varies significantly across producers with different residual capacity, with those equipped with more capacity benefiting more from sharing rules and fee structures favoring specific groups of consumers.[2] We find that raising fees for large consumers reduces their participation, which lowers total community welfare but can increase the surplus accruing to small consumers. This highlights a core tension in energy community design, that is, balancing efficiency with equity. When the EC governance's goal is to maximize total surplus, the model suggests that favoring net producers —particularly through generous surplus shares and low participation fees for large consumers— enhances overall welfare. Nonetheless, this conflicts with equity objectives, especially those aimed at supporting small consumers. Public entities, for instance, may pursue solidaristic goals that prioritize smaller users, even at the cost of some efficiency loss, given the key role of net producers and large consumers in sustaining scale and performance of the EC. Notably, small consumers may still benefit under producer-favoring rules if high fees discourage large consumer participation, making more energy available for smaller users. If the promoter instead prioritizes total consumer surplus, large consumers are preferred due to their profitability, while serving small consumers is less attractive because of sharing congestion costs. When the promoter is also a community participant, the governance choices could tend to reflect their own position. For instance, a large consumer acting as promoter will likely advocate for lower fees and favorable allocation rules, while a net producer will support designs that enhance production incentives. These dynamics expose a fundamental trade-off between efficiency, inclusiveness, and long-term sustainability in EC governance.

The paper is structured as follows. Section 2 situates our contribution within the existing literature on energy communities. Section 3 introduces a streamlined version of the model with a mass of homogeneous net consumers, each with a unit energy demand, to highlight the core logic of our framework. Section 4 characterizes the equilibrium in terms of both individual and total energy contributions within the

[2] In our model extension with consumer heterogeneity, this applies to large consumers due to their more efficient energy exchange.

EC. Section 5 extends the model by incorporating a limited number of consumers with larger energy needs, thereby accounting for the presence of energy-intensive industries. In Section 6, we discuss how the promoter's priorities in setting economic incentives for various EC members influence both aggregate and individual welfare within the community. Finally, Section 7 presents concluding remarks and potential directions for future research.

2 A brief literature review

The primary challenge in our theoretical investigation lies in translating into economic terms a series of individual behaviors and choices that, according to much of the existing literature on energy communities, are often driven by non-economic motivations (such as environmental concerns, solidarity, or identity) rather than purely economic factors (see Soeiro and Dias, 2020; or Karytsas and Theodoropoulou, 2022, among others). The reduced-form approach employed in this paper is specifically designed to address this challenge. This also helps explain why we focus not so much on the extensive margin of participation —which concerns whether net producers choose to join the energy community—, but rather on the intensive margin. Specifically, we examine the amount of energy that net producers decide to contribute to the community, rather than their choice to join or not. The implicit assumption is that net producers, when making this decision, are more responsive to and influenced by the economic factors at play compared to net consumers, who may be more motivated by non-economic considerations.[3]

Prior research has examined the mechanisms by which economic benefits are allocated to decentralized energy market (see Lambin 2020) or among EC participants. The literature has explored various approaches, including Nash bargaining solutions in Stackelberg game settings (see Anoh et al., 2019; Paudel et al., 2018; or Liu et al., 2018) and market-based mechanisms rooted in auction theory (Lin et al., 2019; Chen et al., 2019). Rather than imposing a specific benefit-sharing rule, our model treats this allocation as an endogenous outcome. This approach preserves analytical tractability while accommodating the diversity of governance structures observed across ECs, allowing us to examine how different economic incentives shape energy-sharing behavior without constraining the analysis to a predefined institutional setting.

There are several strands of both economic and non-economic literature on energy communities, to which our analysis relates, although with different degrees of alignment. These include research on the optimal size of energy communities, decision-making processes for membership and expansion, the efficiency of energy-sharing mechanisms, the role of community managers, and challenges related to energy storage.

In the context of EC participation and expansion, a key factor that has been highlighted in the literature is the alignment between energy consumption and production patterns (see, for instance, Mustika et al., 2022). Optimizing energy sharing through consumption matching analysis plays a crucial role in maximizing economic benefits for EC members. This issue is particularly relevant for photovoltaic (PV)-based systems, where energy generation is inherently intermittent and follows predictable peak periods. Building on this insight, our framework considers a setting in which heterogeneous consumers evaluate their participation based on the net benefit of joining the EC, subject to a demand-matching constraint. Meanwhile, net producers determine the volume of energy they contribute by maximizing their own profit, balancing internal sharing incentives against potential revenues from grid sales. The most innovative aspect of our paper is capturing the mismatch between demand and supply within the community, and the quantity competition that develops among net producers over this finite de-

[3]This claim is supported by the fact that net producers face clearer economic trade-offs and opportunity costs when allocating their excess energy, having made significant financial investments in generation capacity. Unlike net consumers, they must regularly evaluate the economic returns of community contribution versus grid sales, naturally making economic factors more salient in their decision-making process.

mand through a sort of negative externality –the sharing congestion cost– which introduces a strategic substitutability problem *à la* Cournot.

This inefficiency could be mitigated by investing in storage facilities and mechanisms to enable peak shaving and load shifting. However, such solutions often include high investment costs, technical limitations of current battery technologies, regulatory constraints, security concerns and complex management requirements and therefore might not always be viable.[4] All of this makes energy storage far more expensive and complex for small-scale, local operators, such as energy communities, compared to national grid operators that can leverage economies of scale, thus benefiting of lower per-unit costs and greater access to capital for expensive battery systems. This creates a significant economic disadvantage for ECs when managing intermittent renewable generation, which justifies our decision to model sharing congestion inefficiencies as a key characteristic of the community, rather than of the grid.

Another important strand of the literature examines the role and identity of energy community promoters. Existing studies characterize the promoter as a neutral third-party entity whose objectives are not driven by personal profit but rather by the overall well-being of the community. Their primary responsibilities include coordinating prosumers, managing peak-hour demand, reducing congestion, and optimizing the collective welfare of the EC (Grzanić et al., 2021; Moret and Pinson, 2018; Noor et al., 2018). In line with this perspective, we adopt a framework in which the EC promoter functions as a platform that facilitates energy exchange between net producers and net consumers. Rather than merely acting as an intermediary, the promoter plays an active role in shaping economic incentives (especially in the early stages) by balancing entry fees and distributing shared benefits, ultimately aiming to maximize an objective function that we will more specifically discuss at the end of our analysis.

A last bulk of related literature is the one in the field of industrial organization on Cournot models and quantity competition under capacity constraints (e.g., Maskin and Tirole, 1987). A close relative of our work is Chevalier-Roignant et al. (2015), which also presents an asymmetric Cournot model with capacity constraints. However, while their focus is on dynamic aspects, we concentrate on consumer heterogeneity. This approach allows for a more detailed examination of market incentives, albeit at the cost of simplifying dynamic components. However, these dynamics are less relevant in our context, given the legal framework of ECs in many countries, which restricts producers' ability to engage in repeated profit maximization and instead emphasizes continuous virtual energy exchange. Similarly, Nie and Chen (2012) propose a Cournot competition model with input capacity constraints. Our model differs by imposing constraints on output rather than inputs, better reflecting the nature of ECs, where production relies primarily on renewable energy sources only subject to weather variability. In our setting, the limiting factor is production capacity, which we treat as fixed to simplify the model and avoid introducing additional layers of strategic interaction.

The level of mathematical formalization required by our approach necessitates omitting some factors important for the overall functioning of energy communities, but not essential to the economic mechanism we aim to isolate and study. One example is the issue of generation capacity building and individual investment in energy production plants, investigated among others by Wüstenhagen and Menichetti (2012); Masini and Menichetti (2012); Ozorhon et al. (2018). In our framework, we assume that each economic agent cannot modify their energy demand or production in response to the formation of the EC. This simplifies the focus of the study to short-term dynamics, specifically on individual choices under constraints related to demand and/or supply rigidity.

Our analysis also deliberately set aside considerations related to coalition formation (see Abada et al. 2020) or self-selection into alternative communities. While this may seem like a limitation, we argue that, at this stage, competition among energy communities remains relatively underdeveloped due

[4]Since our model does not incorporate storage, we refer the reader to Khan et al. (2018), Ghiani et al. (2019), and Astier and Lambin (2019) for a deeper understanding of how effective planning and efficient storage systems can enhance demand matching, reduce reliance on the upstream network, and generate additional value for energy community members.

to their still-limited presence. As a result, concerns about coalition formation and strategic selection —central to the literature on bargaining and group formation (e.g., Konishi and Ray, 2003; or Ray and Vohra, 1997)— are less immediately relevant to our framework. Addressing these issues in depth would introduce complexities that risk diverting attention from our primary objective: understanding how economic incentives shape the extent to which net producers contribute their excess energy to the community.

3 Baseline model

3.1 Premises

Our setting is populated by two types of risk-neutral economic agents, all insisting on the same territory, geographically delimited, within which an energy community (EC) is active.

The first consists of a discrete number of prosumers equipped with an autonomous capacity for electricity generation that exceeds their own individual needs. Consequently, they seek to allocate their surplus production either by injecting it into the national grid (in exchange for a remuneration $p > 0$ set by the grid operator) or by sharing it within the energy community (benefiting from the advantages it provides, which we will characterize in more detail later). We assume that such net producers are $n \in \mathbb{N}$ in number and are all symmetric except for their installed production capacity, denoted by $\bar{k}_i \in [0, 1]$.

The second type of agent is instead represented by a unitary mass of *net consumers*, i.e., economic agents who have an electricity demand they cannot meet independently, either due to a lack of autonomous generation capacity or because their capacity is insufficient to cover their individual needs. For now, we assume that such net consumers are identical and each requires one unit of energy, which can be interpreted as the average energy demand of a local representative household in terms of kWh.[5] Even in this case, there is a choice between obtaining electricity from the national grid at the price P —which is reasonably assumed to be higher than what the grid operator pays to the net producers in the case of transfers, i.e., $P \geq p$— or joining an energy community, incurring the associated participation costs.

3.2 The building blocks of our theory

Having established all necessary premises, we can now proceed to introduce the main features of the energy community (EC) along with the decision-making process of producers and consumers.

The energy community. We define an energy community as a group of individuals, households, organizations, or entities (such as local governments and associations) that come together to collectively produce, consume, or share energy in a decentralized manner. The creation —and, by extension, the existence— of the community generates a compelling economic value $V > 0$ *per unit of energy (kWh) shared within the EC*.[6] This economic value may exceed the market price of a unit of energy shared within the EC, depending on whether we also account for other monetary and non-monetary benefits linked to individual and collective participation. Such benefits may include government subsidies, as well as enhanced local energy resilience, sustainability, social capital, and socio-economic inclusion. These specific aspects are left to the reader's interpretation.

[5] In Section 5, we will relax this assumption to provide a more realistic characterization of the market demand side. Specifically, we will introduce a categorization that reflects the dichotomy between the residential and non-residential sectors, as observed in reality.

[6] Note that $V \in (p, P)$ is a necessary condition for a strictly positive profit for both the national grid operator (which pays a unit price p when purchasing the energy surplus form the net producer) and the private energy company that uses the grid to sell energy at unit price P.

Regarding dimensional restrictions, many countries impose limits on the installed capacity of energy communities, particularly with regard to renewable energy generation.[7] As a result, net producers with a particularly large production capacity are excluded from joining, not by their own choice, but due to these exogenous constraints. This brings us to the idea that participants in the EC on the supply side are subject to both geographical boundaries and capacity constraints. Within our framework, these two aspects help justify the presence of a predefined number of (heterogeneous) net producers, as opposed to a mass of (homogeneous) net consumers.

Benefits for EC members. Once established, the energy community sets internal rules regarding the allocation of costs and benefits associated with its creation and operation. As mentioned above, the decision to exchange electricity within the EC generates an economic value of V for every unit of energy supplied and consumed. This value must be distributed between the two sides of the market in a way that ensures a strictly positive demand for energy within the community while balancing efficiency and equity considerations. We denote by $\beta \in [0, 1]$ the share of this value that the EC decides to allocate to the net producers, while the remaining share, $1 - \beta$, is assigned to the net consumers.[8]

From the producer's viewpoint, βV represents the economic benefit associated with the decision to assign a unit of energy to the community rather than to the national grid This benefit should be contrasted with the price p that the grid operator is committed to paying for each kWh transferred to the national grid, should the alternative solution be chosen. From the net consumer's perspective, βV represents the share of the value generated by the transaction within the EC that is left to the counterpart. As a result, it acts as the unitary shadow price of energy sourced from the EC, in contrast to purchasing it from the national grid at price P. However, a comprehensive evaluation of the *net benefit* of joining the energy community must also take into account the associated costs, which are not limited to monetary expenses, as will be further explained below.

Demand side. Net consumers demand one unit of energy, which they can obtain either by joining the EC or by purchasing from the national grid. Participating in the EC grants them a share $(1 - \beta)V$ of the economic value V, while purchasing from the grid yields a benefit $\phi(P)$, where P is the market price. The function ϕ is decreasing in P, reflecting that higher prices reduce the attractiveness of the outside option.[9]

The EC charges a membership fee $F \geq 0$ to cover its fixed operating costs.[10] For simplicity, we assume that F is paid only by net consumers and does not vary with the size of the community.[11] Accordingly, a net consumer will choose to participate if the value received from the EC exceeds their

[7] These restrictions typically aim to ensure fairness, grid stability, and maintain market integrity. They may include (i) maximum capacity limits in terms of kilowatts or megawatts, which defines the scale of an energy community; (ii) geographical limitations on where energy can be generated and shared within the community; and (iii) regulatory thresholds that distinguish energy communities from larger commercial projects.

[8] An example comes from the regulatory framework currently adopted in Italy to support the formation and expansion of renewable energy communities (RECs). A monetary incentive scheme is in place, allowing RECs to benefit from feed-in tariffs applied to each unit of shared energy. This scheme includes a premium consisting of a fixed component (based on the size of the production facility) and a variable component (linked to the market price of energy). As a result, the REC receives a collective reimbursement, while its members continue to pay their energy bills to their private energy providers, as usual. The distribution of this reimbursement among members is then determined by the REC's internal regulations.

[9] The outside option may also capture non-monetary factors—such as inertia, mistrust, or a reluctance to change established habits—which we do not explicitly model.

[10] These typically include capital expenditures for setup, ongoing maintenance, system monitoring, cybersecurity, administrative costs (e.g., billing, customer support, regulatory compliance), and possibly taxes or grid-related fees imposed by national or local authorities.

[11] Under full information and no uncertainty, the promoter can anticipate how choices over fees and surplus-sharing (β) influence participation decisions. This allows them to set F in a way that balances the community's fixed cost burden across expected members.

outside option, that is: $(1-\beta)V - F \geq \phi(P)$.

Supply side. A generic net producer $i = 1, ..., n$ with an installed electricity generation capacity $\bar{k}_i \in [0,1]$ can share within the EC an amount of energy $q_i \in [0, \bar{k}_i]$ produced in excess of their own needs. The associated cost of energy production is given by $c(q_i) = c \cdot q_i$. We normalize the marginal cost c to zero, without loss of generality, to reflect the idea that once the capacity (such as a photovoltaic plant) is installed, energy production does not incur any additional cost. Moreover, we assume that net producers cannot expand or reduce their capacity without incurring prohibitively high fixed costs. This obviously implies that the distribution of residual capacity is assumed as exogenously given and independent of the presence of an energy community.

We now rank all n net producers based on their installed residual capacity, so that index i will denote hereinafter each agent's position within this ranking:

$$0 \equiv \bar{k}_0 < \bar{k}_1 \leq \bar{k}_2 \leq ... \leq \bar{k}_n < \bar{k}_{n+1} \equiv 1. \tag{1}$$

Moreover, we denote the vector of individual residual capacities as $\bar{\boldsymbol{k}} = (\bar{k}_1, \bar{k}_2, ..., \bar{k}_n)^\top \in \mathbb{R}^n_+$, and define the total residual capacity available on the market as $\bar{K} = \sum_{i=1}^n \bar{k}_i$.

Sharing congestion costs. Coordinating members of the community involves managing various activities, including internal and external communication, decision-making, as well as a series of operational tasks. Among these, the most complex challenge is certainly balancing energy supply and demand on an hourly basis. The needs of net consumers may not always align with the contributions of net producers, leading to temporary shortages, rationing, or the need for energy storage, which requires significant investment in suitable infrastructure.[12] In other words, not all the energy that net producers intend to share can actually be utilized within the EC, as peaks in demand and production might not coincide.

To incorporate this crucial issue without sacrificing simplicity, we introduce the concept of allocative inefficiency —specifically, a *sharing congestion cost.* For the sake of tractability, we quantify this cost in an additively separable per-unit reduced form as:

$$C^{SC}(Q, n) = b_0 \cdot n + b_1 \cdot Q, \tag{2}$$

where the first term captures the inefficiency arising from competition among a number n of energy contributors, while the second term accounts for the inefficiency related to the total quantity of energy shared and consumed within the EC (i.e., $Q = \sum_{i=1}^n q_i$). This inefficiency factor influences the net producer's decision by "eroding" part of the benefit βV received for each unit of energy contributed to the EC, rather than to the national grid.

Intuitively, this intangible cost increases with the total energy exchange among EC members, as capacity mismatches and coordination challenges grow with the size of the community and the volume of transactions. In practice, the quantity-related component of $C^{SC}(Q, n)$, namely $b_1 \cdot Q$, represents a competitive mechanism modeled through a Cournot-style interaction. Given a fixed amount of energy available within the community, part of the economic value generated by the exchange is lost due to competition among net producers for a finite demand at any given moment. This formulation *à la* Cournot also enables us to —indirectly—induce shortages also on the consumer side, reflecting the residual demand logic that underlies strategic quantity competition.[13]

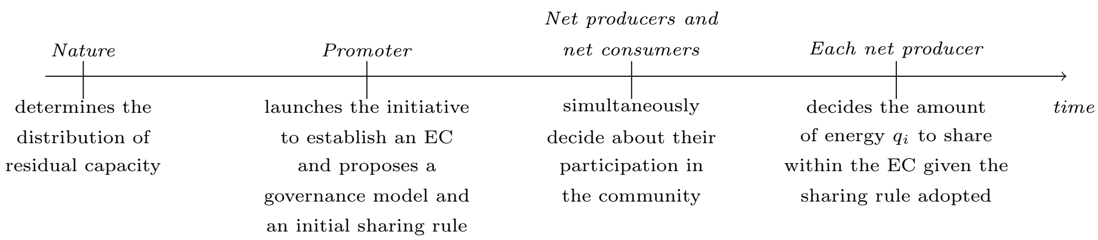
[12] Investment in storage capacity by the energy community entails various complexities and negotiations among EC members that extend beyond the scope and purpose of our analysis. Consequently, this specific aspect is not explicitly addressed in our model.

[13] Under Cournot competition, producers strategically limit their output, preventing the full satisfaction of

Timing of the model. The time structure of our theoretical model is depicted in Figure 1. The classification of each agent as either a net consumer or a net producer —and, in the latter case, their available residual capacity— results from past decisions made before the promoter initiated the creation of an energy community in the target area.

We assume that at some point a promoter launches a campaign to promote the birth of an energy community.[14] This campaign includes publishing a public notice that outlines economic aspects, such as participation fees and the allocation of financial and economic benefits among members. [15] By providing this information, all agents on both sides of the market can make informed decisions about whether to join. Finally, net producers determine the amount of energy to contribute to the EC, given the set of economic incentives they face, recalling that participation in the community does not prevent net producers from also supplying energy to the national grid. If the demand from EC members is insufficient to absorb their available capacity, or if selling to the national grid is simply more profitable, they may choose to allocate part of their energy production externally.

Figure 1: Timing of the model



4 Equilibrium analysis

4.1 Pre-conditions for the equilibrium

Participation decisions of individual net consumers are based on a simple cost-benefit analysis. Given that each consumer demands a single unit of energy, they are all symmetric and their mass is normalized to one, this comparison gives rise to the following internal demand function for the EC, which is perfectly inelastic:

market demand. As a result, consumers face a residual demand that remains unmet. In this setting, each producer's output acts as a strategic substitute for the others: when one producer increases its quantity, the optimal response for others is to decrease theirs. This interdependence in production decisions arises from the competition over a finite demand, leading to inefficiencies and a departure from the socially optimal allocation of resources.

[14] The role of the EC promoter extends beyond simply launching the initiative. It also involves coordinating the establishment phases, recruiting members, managing bureaucracy, and facilitating dialogue with institutions. Moreover, promoters often provide leadership in initial decision-making and help define organizational models and technological solutions. In terms of identity, public entities and local administrations in Italy frequently serve as promoters, while in Northern Europe, many energy communities have emerged from initiatives led by citizens or local cooperatives. The landscape is highly diverse, also encompassing small and medium enterprises (SMEs). Major energy producers can also act as promoters, although this model is less common.

[15] Once the EC is established, internal governance rules—often requiring democratic approval—must comply with EU regulations and national authorization procedures. These may allow changes to the initial sharing rule, potentially reshaping membership. Given the diversity of real-world governance models, we abstract from this complexity and assume the promoter's initial proposal remains in place.

$$Q^D = \begin{cases} 1 & \text{if } (1-\beta)\cdot V \geq F + \phi(P) \\ 0 & \text{otherwise} \end{cases}$$

Obviously, a strictly positive aggregate demand Q^D materializes only if two necessary but not sufficient conditions are met. First, the residual installed capacity of net producers willing to join the EC must be sufficient to cover this demand. Second, in the distribution of the surplus generated within the community, net consumers must receive a share large enough to compensate for their outside option, while covering the individual participation fee. To ensure the existence of the EC, we assume from this point onward that this condition holds, which implies:

$$\beta \leq 1 - \frac{F + \phi(P)}{V} \leq \underline{\beta}. \tag{3}$$

On the other side, a generic net producer i who shares a quantity q_i with the EC and sells the remaining $\bar{k}_i - q_i$ to the grid obtains the following payoff:

$$\Pi_i(q_i, Q_{-i}, \bar{\boldsymbol{k}}) = [\beta V - \underbrace{C^{SC}(Q,n)}_{=b_0\cdot n + b_1 \cdot Q}] \cdot q_i + p \cdot (\bar{k}_i - q_i). \tag{4}$$

In the equation above, Q represents the total volume of energy shared within the community, divided into the quantity q_i supplied by net producer i, and the amount allocated by all other $n-1$ net producers, i.e., $Q_{-i} = \sum_{j\neq i} q_j$. The term $\bar{k}_i - q_i$ denotes the portion of producer i's generation capacity that is instead supplied to the national grid, earning a unit price p. Finally, the first term on the right-hand side of equation (4), namely $\beta V - b_0 n - b_1 Q$, represents the net shadow price of a unit of energy shared within the community from the perspective of the net producer, incorporating the effects of the sharing congestion externality that arises with a total volume Q of energy exchanges.

It is evident that, at the margin, the decision to allocate a unit of energy to the community or to the national grid depends on the relative marginal profitability of these two options. Sharing within the EC is preferable if and only if $\beta V - C^{CS}(n,Q) \geq 0$. This means that, given the total shared quantity Q and the associated sharing congestion cost, the share of surplus allocated to net producers by the EC is sufficiently high. This condition can be expressed as:

$$\beta \geq \frac{p + b_0 n + b_1 Q}{V} \equiv \underline{\beta}. \tag{5}$$

Equations (3) and (5) suggest that, to ensure participation on both sides of the market, the promoter must set the share of surplus allocated to net producers within a specific range, defined as:

$$\beta \in \left[\underline{\beta}, \overline{\beta}\right] \cap [0,1].$$

This range is valid only if the sharing congestion inefficiency remains sufficiently limited for a given size of the energy community. More specifically, the severity of this externality must obey the following condition:

$$C^{SC}(Q,n) \leq V - F - \phi(P) - p \equiv \overline{C^{SC}}. \tag{6}$$

A first result can therefore be established.

Lemma 1 *An energy community can exist and operate if and only if the resulting sharing congestion inefficiency remains sufficiently limited. The maximum tolerable externality $\overline{C^{CS}}$ depends on:*

- *the price of energy sold to and purchased from outside the community, represented by p and P, respectively;*

- *the fixed operating costs of the community, which are recovered through membership fees F;*
- *the economic value V of every unit of energy exchanged within the EC.*

Proof. The claim directly follows from equation (6). ■

Lemma 1 defines a critical viability threshold for energy communities, showing how market conditions, operational efficiency, and scale combine to determine whether such a community can form and sustain itself. To clarify the intuition behind this result, consider a limiting case in which the fixed operating costs of the energy community are negligible, and each unit of energy carries the same economic value regardless of whether it is sourced from within the community or from the national grid. In this scenario, membership fees can be considered minimal and effectively ignored (i.e., $F = 0$). The value of the net consumer's outside option thus simplifies to $\phi(P) = V - P$, with V now encompassing energy acquired from both sources. Under these assumptions, equation (6) reduces to a simpler form: $C^{SC}(Q, n) \leq (P - p)$.

The key takeaway from this result is that the inefficiency due to sharing congestion must be smaller than the grid price spread between purchase and feed-in rates (recall $p < V < P$). This condition underscores a fundamental trade-off in energy communities: as the volume of energy exchanges Q or the number of producers increases, the maximum tolerable level of sharing congestion decreases. Intuitively, larger energy communities with higher volumes of internal exchange must operate more efficiently—or invest in additional storage capacity to mitigate inefficiencies—to remain viable. Once fixed costs F are reintroduced, the condition becomes even more stringent, since these costs must be covered through membership fees, thereby reducing the net benefit of participation. Similarly, if we acknowledge a non-monetary premium associated with locally sourced energy—allowing V to differ between community-sourced and grid-sourced electricity—the maximum acceptable level of inefficiency rises in proportion to this added value.

4.2 Optimal individual contribution

We can now analyze the quantity that each net producer will contribute to the energy community in equilibrium, given their own generation capacity and that of others. By aggregating the individual decisions of the n net producers, we will then determine the total amount of energy available within the EC. As mentioned earlier, net producers in the community compete in a Cournot fashion, selecting their contribution q_i while adhering to the individual capacity constraint: $0 \leq q_i \leq \bar{k}_i$. Following the steps reported in the appendix, we can demonstrate what follows.

Proposition 1 *Assuming $\beta V \geq p$, all n net producers will contribute a strictly positive amount of energy to the community.*

(i) A number $n_U = n - \sum_{i=0}^{n} \mathbb{1}_{\overline{C_i^{SC}} \leq \beta V - p}$ of them will be unconstrained in their contribution, and will supply a quantity

$$q^*_{i,U} = \frac{\beta V - b_0 n - p}{b_1 \cdot (n_U + 1)} - \frac{\sum_{i=0}^{n} \bar{k}_i \cdot \mathbb{1}_{\overline{C_i^{SC}} \leq \beta V - p}}{(n_U + 1)}, \tag{7}$$

where $\overline{C_i^{SC}} \equiv b_1 \cdot \left[(n - i + 2) \cdot \bar{k}_i + \sum_{j=0}^{i-1} \bar{k}_j\right] + b_0 n$.

(ii) The remaining $n - n_U$ net producers will be constrained in their contribution, which means that they will supply their entire residual capacity, i.e., $q^*_{i,C} = \bar{k}_i$.

Proof. See Appendix (A.1). ■

To better understand Proposition 1, it is useful to discuss the threshold $\overline{C_i^{SC}}$, which is the individual counterpart of the threshold value $\overline{C^{SC}}$ in condition (6). This threshold represents the maximum level of congestion externality that producer i is willing to tolerate in order to contribute to the community.[16] When, given producer i's contribution q_i and that of all other producers, the total internal exchanges generate an externality $C^{SC}(Q,n) \geq \overline{C_i^{SC}}$, then contributing to the community is no longer the most profitable option for i: delivering energy to the national grid becomes preferable. In other words, a net producer may choose to limit their contribution to the community and redirect energy to the grid in order to avoid excessive sharing congestion costs.

The threshold for each net producer is linked to their relative residual capacity. For more constrained net producers (those with lower rank i), it is reasonable to assume that the constraint does not bind. This means they will share their entire excess supply within the EC, as they will never encounter a situation where limiting their input is necessary to maintain profitability of this option. Conversely, net producers with greater residual capacity supply larger quantities and may reach a point where they need to truncate their deliveries, redirecting part of their energy to the national grid to avoid exceeding their optimal participation level. This creates an interesting dynamic. A subset $n_U \leq n$ of unconstrained contributors (net producers with relatively high rank i) will strategically balance their allocations between the EC and the grid to maximize their returns; while the remaining $n - n_U$ constrained producers (those with relatively low i) will fully allocate their available capacity to the energy community.

The optimal individual contribution in equation (7) has a straightforward Cournot-type interpretation: each net producer allocates a lower quantity as others supply more. This is evident from (i) the presence of the number of unconstrained contributors (n_U) in the denominator of the first term of the equation; and (ii) the fact that the total quantity supplied by constrained contributors, namely $\sum_{i=0}^{n} \bar{k}_i \cdot \mathbb{1}_{\overline{C_i^{SC}} \leq \beta V - p}$, shifts the residual demand faced by each of the others. Unsurprisingly, a larger share of the economic value of shared energy allocated to net producers (βV) positively affects q_i^*, while higher sharing congestion costs reduce the quantity supplied by each net producer.

4.3 Optimal sharing rule and surplus distribution

We can now examine how individual choices of contribution to the EC map into the overall aggregate-level outcome, which defines the total volume of internal exchanges within the community. By aggregating individual contributions $q_{i,U}^*$ and $q_{i,C}^*$ across all net (constrained and unconstrained) contributors, the total amount of energy shared turns out to be:

$$Q^* = \overbrace{\sum_{i=0}^{n} \bar{k}_i \cdot \mathbb{1}_{\overline{C_i^{SC}} \leq \beta V - p}}^{\substack{\text{total quantity supplied by} \\ \text{constrained contributors}}} + \overbrace{n_U \left(\frac{\beta V - b_0 n - p}{b_1 \cdot (n_U + 1)} - \frac{\sum_{i=0}^{n} \bar{k}_i \cdot \mathbb{1}_{\overline{C_i^{SC}} \leq \beta V - p}}{(n_U + 1)} \right)}^{\substack{\text{total quantity supplied by} \\ \text{unconstrained contributors}}} =$$
$$= \frac{1}{n_U + 1} \cdot \left(n_U \left(\frac{\beta V - b_0 n - p}{b_1} \right) + \sum_{i=0}^{n} \bar{k}_i \cdot \mathbb{1}_{\overline{C_i^{SC}} \leq \beta V - p} \right) \tag{8}$$

A simple comparative statics exercise yields a new theoretical result.

Lemma 2 *The total amount of energy shared within the energy community:*

(i) decreases with the unit price of energy delivered to the grid (p) and the intensity of the sharing congestion externality (b_1 and b_0);

[16] This level is formally reached when all net producers with residual capacity lower than i contribute their entire excess supply to the community (i.e., $q_j = \bar{k}_j$ for all $j = 0, \ldots, i-1$), while all those with greater residual capacity contribute an amount equal to the maximum energy that producer i can contribute (i.e., $q_h = \bar{k}_i$ for all $h = i, \ldots, n$).

(ii) increases with the economic value of each unit of energy exchanged within the EC (V) and the share of this value that is appropriated by net producers (β).

Proof. The lemma follows directly from analyzing the sign of the partial derivatives of equation (8) with respect to the relevant variables. ■

The interpretation of Lemma 2 is, overall, quite intuitive. When the remuneration offered by the national grid operator is particularly high, net producers are more inclined to sell their energy externally rather than participate in local energy sharing within the community. Similarly, greater inefficiency due to sharing congestion externalities discourages participation in energy sharing, as it reduces the net benefits of exchanging energy within the community. Conversely, the unit value of energy V has a positive impact on the amount of energy exchanged within the community, for obvious reasons. A similar reasoning applies to the share β allocated to net producers. However, a more detailed discussion is required in this case. In our highly simplified mode with homogeneuous consumers, the energy community can be established as long as the participation fee F is set to meet the participation constraint of net consumers, as defined in equation (3). To satisfy this constraint, we can take one of two approaches. First, we could assume a given level of fees F and determine the maximum share β that can be allocated to net producers while still ensuring that all net consumers choose to participate. Alternatively, for a given choice of β, we could determine the maximum fee F that net consumers can be charged while still encouraging their participation.

The choice of the sharing rule directly affects the participation of net producers, which in turn has significant implications for both the total surplus generated within the energy community (EC) and the overall volume of energy exchanges, denoted as Q. The allocation of β plays a crucial role in incentivizing net producers to contribute as much of their residual capacity as possible to the EC. Unlike net consumers, who decide only whether to participate, net producers also determine how much energy to supply to the community.

Assuming that participation constraints are satisfied on both sides of the market, the total surplus accruing to the n active net producers is given by

$$\mathcal{W}^{prod} = \sum_{i=1}^{n} \left[\beta V - C^{SC}(Q^*)\right] \cdot q_i^* = \left[\beta V - C^{SC}(Q^*)\right] \cdot Q^*, \tag{9}$$

while the total surplus accruing to net consumers is

$$\mathcal{W}^{cons} = [(1-\beta)V - F] \cdot Q^*. \tag{10}$$

An energy community (EC) governed by a dedicated promoter or internal body may weigh the welfare of producers and consumers differently, depending on the community's goals or social priorities. To capture this, we introduce a parameter $\epsilon \in (0,1)$, representing the promoter's relative preference for consumers. A higher ϵ places more emphasis on consumer surplus in the overall objective.

The resulting welfare function combines producer and consumer surpluses, adjusted by this preference weighting:

$$\mathcal{W}^{EC} = (1-\epsilon) \cdot \mathcal{W}^{prod} + (1+\epsilon) \cdot \mathcal{W}^{cons}. \tag{11}$$

The promoter then faces a standard constrained optimization problem, choosing β to maximize $\mathcal{W}^{EC}$ subject to the participation constraints defined in equations (3) and (5). The standard steps to solve this problem are outlined in Appendix A.2, and the key result is summarized below.

Lemma 3 *The optimal sharing rule is given by:*

$$\beta^* = \beta \in \left[\underline{\beta}, \overline{\beta}\right] \cap [0,1] \quad \textit{such that} \quad \mathcal{W}^{EC} = \frac{b_1 \cdot (Q^*)^2}{n_U} \left[2\epsilon + (1+\epsilon) \cdot n_U\right]. \tag{12}$$

Proof. see Appendix A.2. ■

The main takeaway from Lemma 3 is that both the collective welfare and the volume of energy traded within the EC are concave functions of β. On one hand, a sharing rule that favors net producers encourages their contributions to the community. Nonetheless, this also creates a more significant sharing congestion externality. The optimal share β, as shown in equation (12), strikes the best balance in addressing this trade-off.

As we are about to explore in the next section, introducing heterogeneity among consumers further complicates the balancing of costs and incentives in determining the sharing rule adopted by the community. This, in turn, will make the dynamics of internal market interactions more complex and will pave the way for a more interesting discussion on how the choice of β and F drives the welfare distribution among the various participants.

5 An extension with heterogeneous consumers

5.1 Large vs. small consumers

In practice, the pool of net consumers eligible to join an energy community includes not only households with standard residential electricity usage, but also enterprises—some of which may be highly energy-intensive. To capture this heterogeneity, we divide net consumers into two groups. Alongside a fringe of homogeneous, atomistic consumers representing the residential sector (as in the baseline model), we introduce a finite number $M \in \mathbb{N}$ of large consumers. Each large consumer demands $x_l > 1$ units of energy, where x_l also captures the relative size of their demand compared to that of small consumers, which is normalized to one.

The most significant modification introduced in the model with the inclusion of these new players concerns the sharing congestion externality. As previously mentioned, this externality arises from mismatches between supply and demand, as well as competition among producers over a finite demand. The presence of large consumers within the EC can incentivize net producers to contribute more of their excess supply —potentially up to exhaustion— thereby reducing the inefficiency caused by strategic substitutability, which is inherent in the quantity competition mechanism governing the community. To capture this effect, we extend our reasoning to the limit and assume that, with respect to the total energy traded with large consumers (namely Q_l), the parameter b_1 in equation (2) tends to zero, in contrast to its behavior for energy traded with small consumers (which we denote as $Q_s = Q - Q_f$).[17] As a result, the sharing congestion cost takes on a new form:

$$C^{SC}(n, Q_s) = b_0 n + b_1 Q_s + \underbrace{b_1' Q_f}_{\approx 0}, \tag{13}$$

provided that $b_1' \to 0$. As such, producers find it optimal to always serve all large consumers first and then employ the residual capacity to satisfy the energy requirements of the fringe of atomistic consumers.

Taking the reasoning to the limit by assuming that energy traded with large consumers does not create any allocative inefficiency is not necessarily an overstatement, even if it may appear so. Several factual arguments may indeed be used to support and justify what might seem like an extreme modeling choice. First, small consumers typically require more intricate coordination mechanisms within the EC,

[17] Notably, if there were a single large consumer capable of absorbing the entire installed residual capacity of the n net producers participating in the EC, the sharing congestion inefficiency would be reduced to the sole component $b_0 \cdot n$, which is linked to the coordination problem arising from the number of contributors alone. The typical inefficiency generated by the Cournot mechanism would, in this case, be absent.

increasing the likelihood of inefficiencies. Second, the administrative overhead associated with integrating multiple small consumers into the community is inherently higher, leading to greater inefficiencies compared to dealing with a few large consumers. By modeling the sharing congestion inefficiency as specific to small consumers, we account for real-world complexities in EC dynamics, where smaller participants face greater coordination challenges than large, institutionally sophisticated energy consumers.

A second key innovation in this model extension is that, while the gross unit benefit remains $(1-\beta)V$ for all consumers participating in the community regardless of their energy needs, the membership fees can be differentiated by consumer type. We assume that these fees are set at $F_s \geq 0$ for small consumers and $F_l \geq 0$ for large consumers, allowing for a more flexible cost allocation that reflects differences in their energy consumption profiles and participation dynamics. For now, we do not impose any specific restriction on which participation fee is larger, postponing this discussion to Section 6.

Finally, we introduce idiosyncratic entry costs for large consumers, represented in form of a heterogeneous outside option:

$$\phi_h \sim G[\underline{\phi}, \overline{\phi}],$$

where $h \in \{1, 2, \ldots, M\}$ indexes each large consumer, G denotes a suitable cumulative distribution function, $\underline{\phi}$ and $\overline{\phi}$ represent the lower and upper bounds of this distribution.[18] This assumption captures the diversity in entry costs among large consumers, reflecting factors such as infrastructure requirements, administrative burdens, or alternative energy procurement options.[19] We assume that individual entry costs are known and observable by all players in the market and that, without loss of generality, it is possible to establish a ranking among large consumers as follows:

$$\phi_1 \leq \phi_2 \leq ... \leq \phi_M \tag{14}$$

where they are sorted in increasing order of their idiosyncratic entry costs. In light of the various assumptions made in this section, the participation constraint for small consumers remains the same as in the baseline model, whereas for large consumers, it reads:

$$x_l \cdot (1-\beta)V \geq F_l + \phi_h. \tag{15}$$

5.2 Implications on energy demand

The participation constraint described in equation (15) underlies an individual cutoff for each large consumer. This can be expressed as the maximum value of the participation fee that makes the j-th consumer in the ranking indifferent between participating or not participating in the community. The threshold value of this fee can be defined as

$$\overline{F}_l^h = x_l \cdot (1-\beta)V - \phi_h. \tag{16}$$

Using (14) and (16), the overall number of large consumers m_w willing to participate in the EC for a given level of the membership fee F_l is:

$$m_w(F_l) = h \quad \forall\ F_l \in [\overline{F}_l^{h+1}, \overline{F}_l^h]. \tag{17}$$

[18]As previously explained in Section 3.2, the outside option of net consumers depends on the price P which represents the cost of sourcing energy from the national grid. However, the role of P is limited to that of a simple shifter. Therefore, to avoid overly cumbersome notation, we will no longer explicitly indicate that ϕ_j, as well as the bounds $\underline{\phi}$ and $\overline{\phi}$, are functions of this price.

[19]By doing so, it partially mitigates the strong assumption of identical consumption needs among them, allowing for a more realistic representation of their participation dynamics within the energy community.

Such a number is, of course, an integer and corresponds to the rank h, for each participation fee F_l that is weakly lower than the threshold defined in equation (16), but higher than the threshold $\overline{F}_l^{h+1}$ which would induce $h+1$ large consumers to adhere to the EC.[20] The number of large consumers willing to participate does not necessarily coincide with the number that will ultimately be served. This is due to the limited total generation capacity of net producers, which may result in rationing among large consumers. Accordingly, we define the number of large consumers served by the energy community (EC) at any given value of F_l as:

$$m(F_l) = \begin{cases} m_w(F_l) & \text{if } m_w(F_l) \leq \left\lfloor \dfrac{\bar{K}}{x_l} \right\rfloor \\ \bar{m} \equiv \left\lfloor \dfrac{\bar{K}}{x_l} \right\rfloor & \text{otherwise} \end{cases} \tag{18}$$

Here, the floor function denotes rounding down to the nearest integer—specifically, the integer quotient of the total available energy supply $\bar{K}$ and the individual energy demand of each large consumer, x_l.[21] For simplicity, we assume that large consumers are served in order of increasing outside option, up to the point where the capacity constraint becomes binding.[22]

Accordingly, there exists a threshold value of the participation fee, namely $\overline{F}_l$, below which the number of large consumers served by the EC (and their total energy demand) becomes unresponsive to F_l, as total demand reaches the limit imposed by the installed residual capacity of net producers, thus triggering rationing. This means that for any fee $F_l \leq \overline{F}_l$, the number of large consumers served remains fixed at the constant level $\bar{m}$, as the limiting factor is no longer the fee but rather the installed capacity available for allocation within the energy community. This threshold corresponds to

$$\overline{F}_l = x_l \cdot (1-\beta)V - \phi_{\bar{m}}, \tag{19}$$

where

$$\phi_{\bar{m}} = \max \left\{ \phi_j(P) : \ m(F_l) = \bar{m} \equiv \lfloor \frac{\bar{K}}{x_l} \rfloor \right\}_{j=1}^{M}$$

denotes the value of the outside option that is requested to generate rationing in the total energy demand by large consumers.

Given equations (18) and (19), the total quantity of energy demanded by large consumers in equilibrium within the community can be written as a piecewise, monotonically decreasing function of the participation fee F_l, specifically:

$$Q_l^D(F_l) = \begin{cases} m(F_l) \cdot x_l & \text{if } F_l > \overline{F}_l \\ \bar{m} \cdot x_l & \text{otherwise,} \end{cases} \tag{20}$$

provided that this quantity is strictly decreasing for sufficiently large fees $F_l > \overline{F}_l$ and remain constant for $F_l \leq \overline{F}_l$.

[20] Specifically, the number of large consumers willing to participate at the fee F_l is determined by the interval in which the corresponding fee falls between the thresholds for the h-th and $(h+1)$-th consumers.

[21] Recall that while large consumers differ in their outside options, they all share the same energy requirements.

[22] Accordingly, the large consumers who obtain the greatest surplus from their participation will actually be served first. This is in line with a rule such as "first in, first served", which could encourage large consumers with larger surpluses to act more swiftly and decisively in joining the initial call from the promoter.

5.3 Implications on energy supply

Let us now discuss how the modifications introduced on the internal demand side of the community impact net producers' decisions regarding the amount of residual capacity they allocate to the EC. We begin by examining how each producer decides to allocate their capacity between large and fringe consumers, considering the asymmetric capacity constraint at play. The splitting rule adopted by the community establishes a uniform per-unit gross benefit for all consumers, regardless of whether they are large or small. However, serving large consumers entails lower per-unit negative externalities. As a result, prioritizing large consumers is always more profitable, irrespective of individual capacity constraints. It follows that fringe consumers receive the remaining capacity only after the energy needs of the large consumers who have joined the EC are fully met. To derive the efficient energy allocation, we adopt a two-stage approach.

In the first stage, net producers allocate energy to large consumers. As a result, the demand described in equation (20) may constrain some producers. This occurs to producer i when

$$Q_l^D(F_l) \geq \sum_{j=0}^{i-1} \bar{k}_j + (n-i+2)k_i \equiv \overline{Q}_i^D. \tag{21}$$

In contrast, other producers remain unconstrained and face only a portion of the aggregate demand. The residual demand allocated among these unconstrained producers is given by:

$$Q_{U,l}^D \equiv Q_l^D(F_l) - \sum_{i=1}^{n} \bar{k}_i \cdot \mathbb{1}_{\{Q_l^D(F_l) \geq \overline{Q}_i^D\}}.$$

Let $n_{U,l}$ denote the number of unconstrained producers. Each of them supplies an equal share of the residual demand, such that

$$q_{i,U,l}^* = \frac{Q_{U,l}^D}{n_{U,l}},$$

which represents the amount of energy allocated to large consumers by each unconstrained producer.

After serving large consumers, the remaining capacity of each net producer is:

$$\hat{k}_i(F_l) \equiv \max\left\{0, \bar{k}_i - q_{i,U,l}^*\right\}.$$

The second-stage allocation to small consumers follows the same logic as outlined in Proposition 1, and we refer the reader to Appendix A.3 for the detailed derivation. The equilibrium of this two-stage game is formalized in the following proposition, which extends the result of Proposition 1 from Section 4.2 to a setting with two consumer types.

Proposition 2 *Assuming $\beta V \geq p$, all n net producers will continue to contribute a strictly positive amount of energy to the community, even when consumers are divided into two groups with differing energy needs.*

(i) A number $n_{C,l} = \sum_{i=1}^{n} \mathbb{1}_{\{Q_l^D(F_l) \geq \overline{Q}_i^D\}}$ of net producers will reach their contribution limit by the end of stage 1, meaning they will fully allocate their residual production capacity to serving large consumers. Formally, we denote their contribution as $q_{i,C,l}^* = \bar{k}_i$.

(ii) A number $n_{C,s} = \sum_{i=0}^{n} \mathbb{1}_{\overline{C_i^{SC}} \leq \beta V - p} - n_{C,l}$ of net producers will reach their contribution limit by the end of stage 2, meaning they will fully allocate their residual production capacity to serving both large and small consumers. For these producers, the total amount of energy supplied to the community is denoted as $q_{i,C,s}^* = \bar{k}_i = q_{i,U,l}^* + \hat{k}_i$.

(iii) A number $n_U = n - \sum_{i=0}^{n} \mathbb{1}_{\overline{C_i^{SC}} \leq \beta V - p}$ *of net producers will remain unconstrained in their contribution to the community even after stage 2. These producers will share within the EC an amount of energy given by:*

$$q^*_{i,U} = q^*_{i,U,s} + q^*_{i,U,l} \tag{22}$$

where

$$q^*_{i,U,s} = \frac{\beta V - b_0 n_{U,l} - p}{b_1 \cdot (n_U + 1)} - \frac{\sum_{i=0}^{n_{U,l}} \hat{k}_i \cdot \mathbb{1}_{\overline{C_i^{SC}} \leq \beta V - p}}{(n_U + 1)},$$

represents the fraction of their contribution absorbed by small consumers.

Proof. See Appendix A.3. ■

The key insights from Proposition 2 largely mirror those outlined in the discussion of Proposition 1, with only minor adjustments to account for the two-stage allocation process, which prioritizes large consumers.

We conclude our description of the equilibrium by presenting the counterpart of equation (8) for this extended version of our model, that reads:

$$Q^*(F_l) = Q^*_s(F_l) + Q^*_l(F_l), \tag{23}$$

where

$$Q^*_s(F_l) = \frac{1}{n_U(F_l) + 1} \left(n_U(F_l) \left(\frac{\beta V - b_0 \cdot n_{U,l}(F_l) - p}{b_1} \right) + \sum_{i=0}^{n_{U,l}(F_l)} \hat{k}_i(F_l) \mathbb{1}_{\overline{C_i^{SC}} \leq \beta V - p} \right)$$

denotes the overall exchange of energy with small consumers within the EC, while $Q^*_l(F_l) = Q^D_l(F_l)$ represents the volume of exchanges involving large consumers, as determined by the total demand function in equation (18). The last expressions are derived by aggregating the individual contributions from all n net producers participating in the EC at each stage of the allocation process.

We will use this total quantity $Q^*(F_l)$ to derive both the aggregate and individual welfare levels of all EC members, which we will discuss in the next section. These levels are conditional on the sharing rule applied within the community. Note that the total amount of energy shared within the EC —and, consequently, the surplus generated by these exchanges— depends not only directly on β, but also indirectly on the participation fee F_l. The fee influences three variables, specifically n_U, $n_{U,l}$, and $\hat{k}_i$, all of which appear in the equations for $Q^*_s(F_l)$ and $Q^*_l(F_l)$.

6 Governance models and their implications

In our model,the energy contribution choices of net producers are made based on the sharing rule adopted by the community, once it has formed following the participation decisions of individual members on both sides of the market. In turn, these decisions depend on the governance model and the very purpose of the community that it implies. For the sake of simplicity, we will embody the governance and mission of the community in the figure of the promoter, who is the actor responsible —within our model— for formulating the sharing rule proposal on the basis of which all subsequent decisions of the members are developed.

In real-world energy communities, a diverse range of actors can take on the role of promoters. Some communities are led by cooperatives formed by citizens and households, typically aiming to balance benefits among participants. Others are driven by private entities (often also acting as internal net producers) that may be primarily motivated by profit. At the same time, municipalities and other public institutions may pursue broader social objectives, such as maximizing total surplus (a utilitarian approach) or supporting vulnerable consumers (a solidaristic approach). These differing priorities shape the distribution of surplus among participants and have significant implications for both the efficiency and fairness of energy sharing.

By illustrating surplus distribution under any given fee and sharing rule, we can still explore their main implications, particularly by using graphical representations that highlight key outcomes for all participants. In doing so, we distinguish between producer profits (accounting for heterogeneity in generation capacity), consumer surplus (separating small and large consumers), and overall social surplus. This approach allows us to examine potential incentive misalignment across different promoter types and assess their impact on the sustainability and fairness of energy-sharing arrangements.

To structure our discussion, we consider five key scenarios based on the type and objective of the promoter:

i. an external promoter—such as a municipal government—aiming to maximize overall social surplus;
ii. an external promoter with a specific focus on supporting small consumers;
iii. an external promoter prioritizing consumer welfare, regardless of consumer size;
iv. a self-interested promoter who is a net producer within the community;
v. a self-interested promoter who is a large consumer within the community.

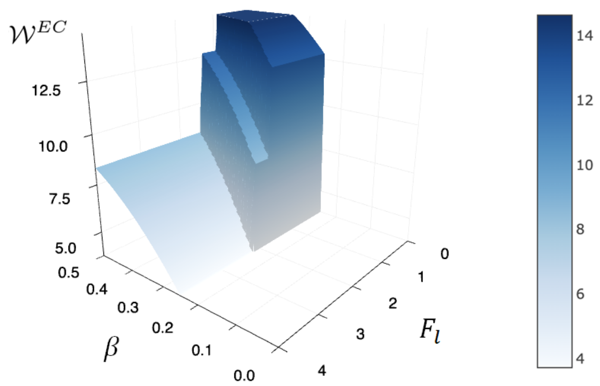
6.1 The cases with an external promoter

When an external promoter undertakes the establishment of an energy community, their objective may be to maximize either the total surplus within the EC or the consumer surplus— with or without giving priority to small consumers. To identify the optimal values of β and F_b for achieving these goals, we provide a graphical representation based on specific values of key model parameters. These include the number of producers (n), the number of large consumers (M), the market price of energy (p), the perceived value of the energy exchanged within the EC (V), the sharing congestion cost parameter (b_1), and the relative demand of large consumers (x_l).

Case i – The promoter cares about total surplus. We begin by examining total surplus at the whole community level, across all possible combinations of the sharing rule β and the fee charged to large consumers, F_l. Figure 2 reveals a clear pattern: total surplus consistently declines as F_l increases, and rises with higher values of β. In plain words, when large consumers face higher participation fees, overall surplus decreases, while allocating a larger share of the surplus to net producers tends to boost total welfare. This finding suggests that, within the framework of our theoretical model, maximizing the EC's total surplus involves (i) favoring producers over consumers, and (ii) favoring large consumers over small ones.

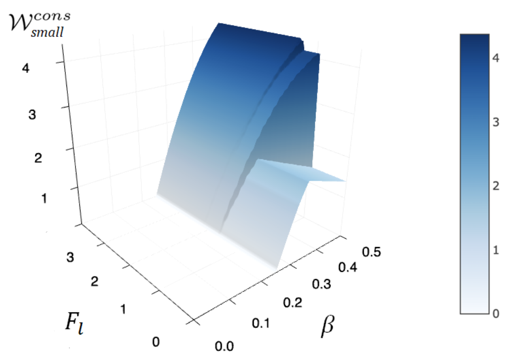
The intuition behind this result is that achieving high levels of energy sharing requires both robust production and substantial consumption. Thus, a local authority aiming to promote a community with the objective of maximizing total welfare should adopt sharing rule that mostly benefit producers. However, this welfare-maximizing choice of β and F_l may conflict with a solidaristic approach, which emphasizes consumer welfare—particularly that of small consumers—thereby highlighting a potential trade-off between overall efficiency and equity in energy-sharing arrangements.

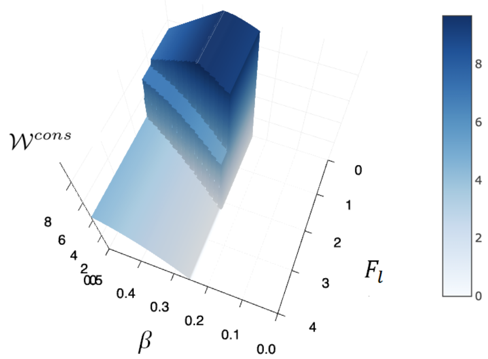
Figure 2: Total surplus of all EC members for any possible combination of F_l and β.*



*The adopted parametrization is: $n = 8$, $M = 6$, $p = 0.25$, $b_1 = 0.025$, $x_l = 3$, $V = 1$.

Figure 3: Small consumer surplus (left) and total consumer surplus (right) created within the EC for any possible combination of F_l and β.*





*Parameters are set at the same levels as in Figure 2.

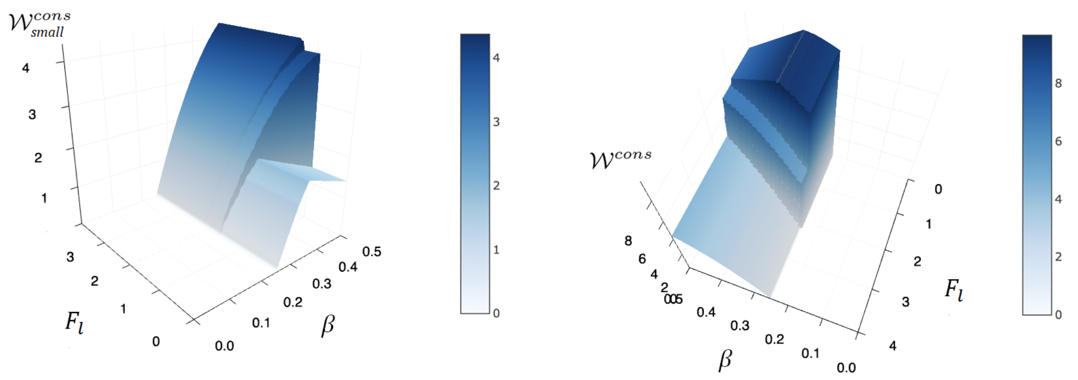
Case ii – The promoter primarily cares about small consumers. A promoter may pursue a solidaristic objective, aiming to maximize the surplus of small consumers. As illustrated in Figure 2, this approach is not efficient from the perspective of total welfare, since net producers and large consumers play a central role in determining the scale and performance of an energy community. Nonetheless, particularly when the promoter is a municipality or another political entity, fostering the engagement of small residential consumers may be essential for ensuring the long-term viability and public legitimacy of the community. In this context, a promoter may reasonably choose to prioritize small consumers.

Figure 4 (Left Panel) illustrates that the surplus accruing to small consumers is concave in β and increases in a stepwise manner with respect to the fee charged to large consumers, F_l. At lower levels of F_l, large consumers demand a substantial portion of the total quantity of energy shared, leaving a limited residual supply for small consumers. Their surplus therefore decreases. However, with a larger membership fee F_l, large consumers face reduced incentives to participate, which in turn reduces their demand. This opens up greater access to shared energy for small consumers, resulting in a corresponding increase in their surplus.

The initial gains observed for small consumers as β increases —regardless of the level of F_l— are consistent with expectations. In our model, a higher value of β increases the relative profitability of intra-community energy sharing compared to grid transactions, generating a mechanical quantity effect. As more energy is allocated to the community, the likelihood that excess energy supply remains available for small consumers (after serving large consumers) rises accordingly.

Case iii – The promoter primarily cares about total consumer surplus. Figure 4 (Right Panel) illustrates the behavior of overall consumer surplus in the baseline scenario. Since it results from the linear combination of two quasi-concave functions (those of large and small consumers), it is itself quasi-concave in β. In addition, the function exhibits a stepwise, monotonic decline with respect to F_l, primarily driven by the surplus dynamics of large consumers. This pattern arises because large consumers are prioritized in the allocation process, and producers can profitably serve them with minimal constraints aside from their residual capacity. By contrast, small consumers can only be served profitably at decreasing rates due to sharing congestion costs. As a result, replacing large consumers with small ones does not always constitute a viable strategy, as it may reduce marginal revenues relative to what net producers could earn by selling excess energy to the national grid.

Figure 4: Small consumer surplus (left) and total consumer surplus (right) created within the EC for any possible combination of F_l and β.*



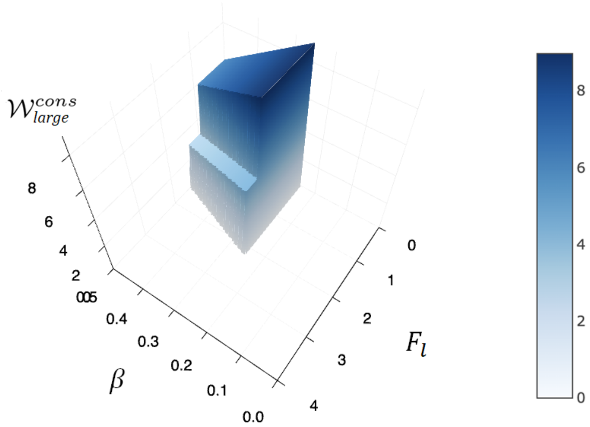
*Parameters are set at the same levels as in Figure 2.

6.2 The cases with an internal promoter

When the promoter is also a prospective member of the energy community, the governance model is likely to reflect their own interests. Depending on whether the promoter is a net consumer or a net producer, their objective will align with the preferences of one side of the market or a specific group within the community. As with external promoters, the design of fee structures and sharing rules remains crucial in shaping welfare distribution across participants, under varying parameter conditions.

Case iv – The promoter is a large consumer. When a large consumer serves as the internal promoter, they are likely to favor choices of F_l and β that ensure substantial energy access for large consumers within the energy community. In our framework, this corresponds to maximizing the surplus of large consumers, which is portrayed in Figure 5. This figure shows that the surplus of large consumers declines in a stepwise fashion as F_l increases, reflecting reduced participation due to higher fees. A similar decline occurs with rising β, as a greater share of the welfare generated within the EC is allocated to net producers, thereby diminishing the benefit that large consumers derive from each unit of exchanged energy. The interaction between F_l and β produces discrete drops at key thresholds, which correspond to shifts in participation and allocation dynamics.

Figure 5: Large consumer surplus created within the EC for any possible combination of F_l and β.*



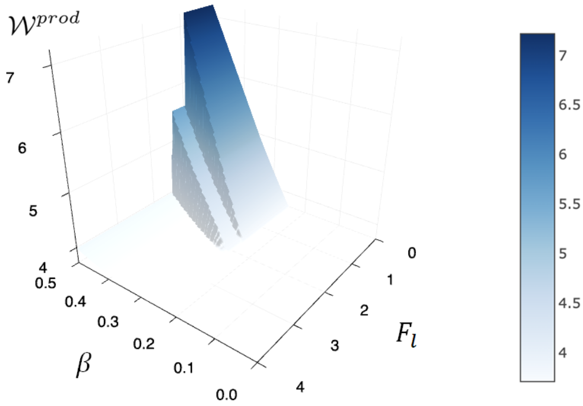
*Parameters are set at the same levels as in Figure 2.

While we frame this scenario around an internal promoter, the same logic applies to an external promoter prioritizing large consumer welfare. We address it here for convenience, recognizing that a policymaker focused on consumer interests might adopt similar approaches. However, this might contrast with a purely utilitarian objective, which seeks to maximize total surplus without favoring specific groups within the community.

Taken together, Figures 2 and 5 highlight a fundamental trade-off in energy community design. Prioritizing large consumers —whether through lower fees or more favorable sharing rules— effectively boosts their participation and secure demand, which is essential for efficient energy allocation. However, this comes at a cost. As more surplus is directed toward large consumers, net producers may receive lower compensation, potentially reducing their willingness to contribute energy. Likewise, small consumers may face limited access to affordable energy, weakening the inclusiveness and perceived fairness of the community. Over time, this imbalance can undermine the broader goals of sustainability, equity, and resilience that energy communities are typically meant to promote.

Case v – The promoter is a net producer. When a net producer acts as an internal promoter, they are likely to support governance models that enhance production incentives, with the aim of maximizing the surplus accruing to energy providers within the EC. While such an approach may increase energy availability and contribute to overall efficiency, it can do so at the expense of consumers (particularly small ones) if the sharing rule disproportionately favors producers.

Figure 6: Total net producer surplus created within the EC for any possible combination of F_l and β.*



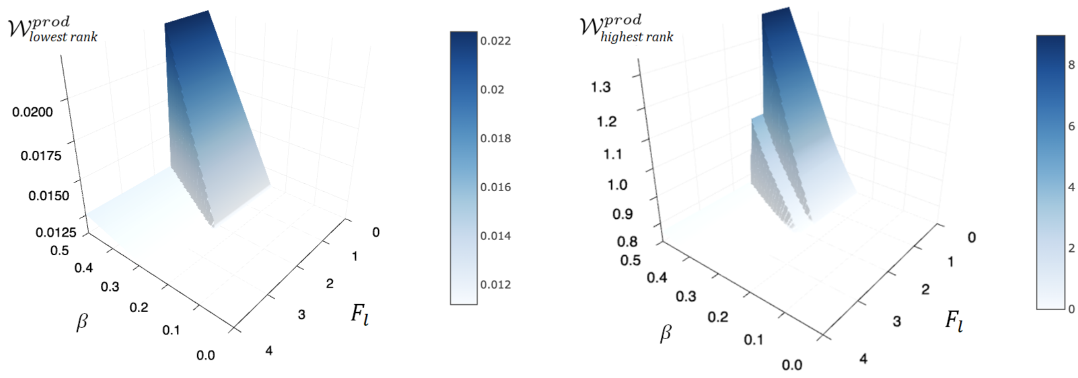
*Parameters are set at the same levels as in Figure 2.

Figure 6 shows that the total surplus of net producers increases monotonically with β across all values of F_l, and also weakly rises as F_l decreases. This pattern emerges because, as long as β remains below the threshold that would breach consumers' participation constraints, net producers can capture a larger portion of the economic value V of each unit of energy shared within the community. This boosts their profitability without substantially discouraging consumer engagement, thus reinforcing their dominant position in the surplus distribution.

Net producers with larger residual capacity benefit more from increases in β and decreases F_l, as they are better positioned to capture a greater share of the surplus generated within the EC. In contrast, net producers with more limited residual capacity experience more modest gains, which may influence their willingness to participate under certain configurations of fees and sharing rules. These dynamics are illustrated in Figure 7, where the Left Panel shows the surplus of the net producer with the lowest rank i, while the Right Panel shows the surplus of the highest rank. A part from size differences, both surplues exhibits a sharp drop once F_l surpasses a critical threshold. At this point, the contribution to the EC becomes less attractive for large consumers, prompting the producer to reallocate energy toward small consumers. However, serving these consumers involves higher sharing congestion costs and coordination issues, which overall tend to reduce the surplus that the net producer may derive from its delivery to the community. The considerations discussed in this section remain robust under a wide range of alternative parameterizations, beyond the specific baseline configuration used to generate all Figures from 2 through 7. We conducted a series of sensitivity analyses by varying individual model parameters—such as the number of producers, consumer composition, energy prices, and cost coefficients—as well as by jointly altering multiple parameters.[23]

[23] These robustness checks consistently confirmed the main findings, with no substantial deviations in the qualitative patterns of welfare distribution across EC participants. While these additional simulations are not included in the main text for brevity, they are available upon request.

Figure 7: Net producer surplus of the contributors with the smallest (left) and largest(right) residual capacity created within the EC for any possible combination of F_l and β.*



*Parameters are set at the same levels as in Figure 2.

7 Conclusion

Energy communities (ECs) are gaining prominence as instruments for decentralizing energy systems. This paper has developed a tractable and parsimonious theoretical framework to analyze the core economic incentives at play within ECs and capture key features observed across European communities, including congestion-sharing externalities, value creation and allocation, and the role of entry fees.

Section 3 has introduced the baseline model, which has been further extended in Section 5 to account for consumer heterogeneity. Our analysis has revealed a central trade-off between maximizing consumer surplus versus fully utilizing production capacity. This tension arises from the adverse effects of cost sharing under congestion. We have further examined in Section 6 how welfare outcomes depend not only on the profitability for net producers of sharing energy within the EC instead of allocating it to the national grid, but also on consumer participation, which is shaped by value sharing mechanisms and entry costs. These dynamics give rise to multiple trade-offs that reflect the broader governance and purpose of the EC.

While the model is deliberately simplified to ensure analytical clarity, this comes with limitations. These open several avenues for future research. A key direction involves examining the intensive margin of participation, in line with ongoing debates around the optimal scale and composition of ECs. A deeper investigation into the drivers of both consumer and producer engagement could enhance our understanding. Moreover, incorporating an endogenous sharing rule —potentially derived from Nash bargaining within the community— could help address some of the trade-offs highlighted in this work and offer a more robust depiction of EC dynamics.

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A Appendix

A.1 Proof of Proposition 1

This Appendix provides a formal proof of Proposition 1 in Section 4.2. Let us begin by defining the profit function for a generic net producer, labeled as the i-th producer, who has an installed residual capacity of $\bar{k}_i$, within a given distribution of generation capacities among the n active producers, that we represent as $\bar{\boldsymbol{k}}$. Suppose that this producer decides to contribute a quantity $q_i \leq \bar{k}_i$ to the community, utilizing any available excess production capacity by selling energy to the grid. Furthermore, assume that the remaining $n-1$ net producers collectively provide an amount of Q_{-i} to the community, such that the total energy exchanged within the community is $Q = q_i + Q_{-i}$. The payoff function for net producer i is the one reported in equation (4), i.e.,

$$\Pi_i(q_i, Q_{-i}, \bar{\boldsymbol{k}}) = [\beta V - b_0 n - b_1 Q] \cdot q_i + p \cdot (\bar{k}_i - q_i).$$

Given the Cournot framework we adopt, the optimal individual contribution q_i^* is such that:

$$\Pi_i(q_i^*, Q_{-i}^*, \bar{\boldsymbol{k}}) \geq \Pi_i(q_i', Q_{-i}^*, \bar{\boldsymbol{k}}) \quad \text{for any } q_i' \neq q_i^*,$$

meaning that the quantity supplied by net producer i to the community must represent the best response to the total amount of energy supplied by the other $n-1$ contributors. Let us now focus on the first term of the payoff function, which captures the net producer's surplus generated through participation and energy sharing within the EC. The gross profitability of each unit of energy contributed to the community can be defined as:

$$\tilde{\Pi}^{EC} = \beta V - b_0 n - b_1 \cdot \sum_{i=0}^{n} \bar{k}_i \cdot \mathbb{1}_{\overline{C_i^{SC}} \leq \beta V - p} \tag{A1.1}$$

where $\overline{C_i^{SC}}$ denotes the threshold for the sharing congestion externality –defined in equation (7)– above which contributing to the EC is no longer profitable.

The net producer problem can be formulated in these terms:

$$\max_{q_i} \Pi_i(q_i, Q_{-i}, \bar{\boldsymbol{k}})$$

subject to the capacity constraint $\bar{k}_i - q_i \geq 0$ and the non-negativity constraint $q_i \geq 0$.

The Lagrangian function of this problem reads:

$$\mathcal{L}(q_i, \lambda_1, \lambda_2) = [\beta V - b_0 n - b_1 Q] \cdot q_i + p \cdot (\bar{k}_i - q_i) + \lambda_1 \cdot (\bar{k}_i - q_i) + \lambda_2 \cdot q_i,$$

whereas the Karush-Kuhn-Tucker conditions are given by:

$$\begin{cases} \frac{\partial \mathcal{L}}{\partial q_i} = 0 \\ \lambda_1(\bar{k}_i - q_i) = 0 \\ \lambda_2 q_i = 0 \\ \lambda_1 \geq 0 \\ \lambda_2 \geq 0 \end{cases}$$

The FOC of this problem reads: $\beta V - b_0 n - b_1 Q_{-i} - 2b_1 q_i - p = 0$. Considering both interior and corner solutions, we can characterize the best response strategy of each contributor as follows

$$q_i^{br}(Q_{-i}) = \begin{cases} 0 & \text{if } C^{SC}(Q_{-i}) \geq \beta V - p \\ \frac{\beta V - b_0 n - p}{2b_1} - \frac{1}{2} \cdot Q_{-i} & \text{if } C^{SC}(Q_{-i}) \in (\beta V - p - 2b_1 \bar{k}_i;\ \beta V - p] \\ \bar{k}_i & \text{if } C^{SC}(Q_{-i}) \leq \beta V - p - 2b_1 \bar{k}_i \end{cases}$$

where $C^{SC}(Q_{-i}) = b_0 n + b_1 Q_{-i}$ represents the negative externality associated with the volume of energy supplied to the community by all other $n-1$ contributors. Since the threshold $\overline{C_i^{SC}}$ is defined individually based on each net producer's residual generation capacity, it may occur that $C^{SC}(Q_{-i}) \leq \overline{C_i^{SC}}$ for some producers, while $C^{SC}(Q_{-i}) \geq \overline{C_i^{SC}}$ for others. This implies that a subset of net producers, denoted as $n_U \leq n$, will be unconstrained in their contributions to the EC, whereas the remaining $n_C = n - n_U$ will be constrained, i.e., they will contribute their entire residual capacity to the community.

Following the standard approach used to solve Cournot-type models, we can determine the optimal sharing decision of each net producer, which is given by

$$\begin{aligned} q_i &= \frac{\beta V - b_0 n - b_1 \cdot \left(\sum_{j=0}^{i-1} \bar{k}_j\right) - b_1 \cdot \left(\sum_{j=i+1}^{n} q_j\right) - p}{2b_1} = \\ &= \frac{\beta V - \left[b_0 n - b_1 \sum_{j=0}^{i-1} \bar{k}_j\right] - p}{2b_1} - \frac{1}{2}(n_U - 1) q_i. \end{aligned}$$

As the quantity of unconstrained contributors is symmetric, we can omit index i and obtain:

$$(n_U + 1) q = \frac{\tilde{\Pi}^{EC} - p}{2b_1} \quad \Leftrightarrow \quad q^* = \frac{\tilde{\Pi}^{EC} - p}{b_1 (n_U + 1)}. \tag{A1.2}$$

At the equilibrium, the optimal individual contribution therefore corresponds to

$$q_i^* = \begin{cases} 0 & \text{if } C^{SC}(Q_{-i}^*) \geq \beta V - p \\ \frac{\tilde{\Pi}^{EC} - p}{b_1 (n_U + 1)} & \text{if } C^{SC}(Q_{-i}^*) \in (\beta V - p - 2b_1 \bar{k}_i;\ \beta V - p] \\ \bar{k}_i & \text{if } C^{SC}(Q_{-i}^*) \leq \beta V - p - 2b_1 \bar{k}_i. \end{cases}$$

where the interior solution –here expressed as in equation (A1.2)– can be rewritten as equation (7) by simply substituting $\tilde{\Pi}^{EC}$ with its expression from equation (A1.1).

The total quantity of energy shared within the EC can be easily calculated as follows:

$$\begin{aligned} Q^* &= \sum_{j=0}^{i-1} \bar{k}_j + \sum_{l=i}^{n} q_i^* = \\ &= \sum_{j=0}^{i-1} \bar{k}_j + \underbrace{(n - i + 1)}_{= n_U} \cdot \frac{\tilde{\Pi}^{EC} - p}{b_1 (n_U + 1)}, \end{aligned}$$

from which it is immediate to derive equation (8) in Section 4.3.

We conclude this appendix by quantifying the net producer' payoff resulting from their optimal allocation of excess energy supply between the EC and the national grid. Starting from equation (4) and then replacing q_i^* and Q^* with their expressions from equations (7) and (8), one gets:

$$\begin{aligned}
\pi_i^* &= [\beta V - b_0 n - b_1 Q^*] \cdot q_i^* + p \cdot (\bar{k}_i - q_i^*) = \\
&= \left[\beta V - b_0 n - b_1 \cdot \left(\sum_{j=0}^{i-1} \bar{k}_j + n_U \cdot q^*\right)\right] \cdot q^* + p \cdot (\bar{k}_i - q^*) = \\
&= \left[\tilde{\Pi}^{EC} - b_1 n_U \cdot \frac{\tilde{\Pi}^{EC} - p}{b_1(n_U+1)} - p\right] \cdot \frac{\tilde{\Pi}^{EC} - p}{b_1(n_U+1)} + p \cdot \bar{k}_i = \\
&= \frac{(\tilde{\Pi}^{EC} - p)^2}{b_1(n_U+1)^2} + p \cdot \bar{k}_i
\end{aligned} \tag{A1.3}$$

Equation (A1.3) obviously applies to net producers who are unconstrained in their contribution to the EC, as they optimally choose to allocate part of their residual capacity also to the national grid (i.e., $q_i^* < \bar{k}_i$). For those contributors who are instead constrained ($q_i^* = \bar{k}_i$), the payoff function evaluates to

$$\begin{aligned}
\pi_i^*|_{q_i^* = \bar{k}_i} &= [\beta V - b_0 n - b_1 Q] \cdot \bar{k}_i = \left[\beta V - b_0 n - b_1 \cdot \left(\sum_{j=0}^{i-1} \bar{k}_j + n_U \cdot q^*\right)\right] \cdot \bar{k}_i = \\
&= \left[\tilde{\Pi}^{EC} - b_1 n_U \cdot q^*\right] \cdot \bar{k}_i = \left[\tilde{\Pi}^{EC} - b_1 n_U \cdot \frac{\tilde{\Pi}^{EC} - p}{b_1(n_U+1)}\right] \cdot \bar{k}_i = \frac{\tilde{\Pi}^{EC} + n_U p}{(n_U+1)} \cdot \bar{k}_i.
\end{aligned}$$

These results can be consolidated into the following equilibrium profit profile:

$$\Pi_i^*(q_i^*, Q_{-i}^*, \bar{\boldsymbol{k}}) = \begin{cases} 0 & \text{if } C^{SC}(Q_{-i}^*) \geq \beta V - p \\ \frac{(\tilde{\Pi}^{EC} - p)^2}{b_1(n_U+1)^2} + p\ \bar{k}_i & \text{if } C^{SC}(Q_{-i}^*) \in (\beta V - p - 2b_1\bar{k}_i;\ \beta V - p] \\ \frac{\tilde{\Pi}^{EC} + p\ n_U}{(n_U+1)} \bar{k}_i & \text{if } C^{SC}(Q_{-i}^*) \leq \beta V - p - 2b_1\bar{k}_i. \end{cases}$$

A.2 Proof of Lemma 3

This Appendix presents the proof of Lemma 3 from Section 4.3. To establish our result, we must first of all demonstrate that the total welfare generated within the EC, denoted as $\mathcal{W}^{EC}$, is a concave function of β, for all possible values of the preference parameter $\epsilon \in (0,1)$, which reflects the EC governance bias towards net consumers.

Having expressed $\mathcal{W}^{EC}$ as a weighted sum of the surpluses of net producers and net consumers, as indicated in equation (11), we find that its first derivative with respect to β is:

$$\frac{\partial \mathcal{W}^{EC}}{\partial \beta} = (1-\epsilon) \cdot \frac{\partial \mathcal{W}^{prod}}{\partial \beta} + (1+\epsilon) \cdot \frac{\partial \mathcal{W}^{cons}}{\partial \beta} \tag{A2.1}$$

Based on equation (9), the derivative of the producer surplus component can be written as:

$$\frac{\partial \mathcal{W}^{prod}}{\partial \beta} = \left[V - b_1 \frac{\partial Q^*}{\partial \beta}\right] Q^* + \frac{\partial Q^*}{\partial \beta} \cdot (\beta V - b_0 n - b_1 Q^*).$$

By equation (8), it follows immediately that $\partial Q^*/\partial\beta = \frac{n_U V}{(n_U+1)b_1}$. This yields:

$$\begin{aligned}\frac{\partial \mathcal{W}^{prod}}{\partial \beta} &= \left[V - b_1 \frac{n_U V}{(n_U+1)b_1}\right] Q^* + \frac{n_U V}{(n_U+1)b_1} \cdot (\beta V - b_0 n - b_1 Q^*) \\ &= VQ^* + \frac{n_U V}{(n_U+1)b_1} \cdot (\beta V - b_0 n - 2b_1 \cdot Q^*) \end{aligned} \tag{A2.2}$$

By differentiating further with respect to β, we finally obtain:

$$\begin{aligned}\frac{\partial^2 \mathcal{W}^{prod}}{\partial \beta^2} &= V \cdot \frac{\partial Q^*}{\beta} + \frac{n_U V}{(n_U+1)b_1} \cdot \left(V - 2b_1^2 \frac{\partial Q^*}{\beta}\right) \\ &= \frac{2n_U V^2}{(n_U+1)b_1} - 2\left[\frac{n_U V}{(n_U+1)b_1}\right]^2\end{aligned}$$

We can now focus on the consumer surplus component, which reads:

$$\begin{aligned}\frac{\partial \mathcal{W}^{cons}}{\partial \beta} &= - V \cdot Q^* + \frac{\partial Q^*}{\partial \beta} \cdot [(1-\beta)V - F] \\ &= - V \cdot Q^* + \frac{n_U V}{(n_U+1)b_1} \cdot [(1-\beta)V - F]\end{aligned} \tag{A2.3}$$

The second derivative with respect to β is

$$\begin{aligned}\frac{\partial^2 \mathcal{W}^{cons}}{\partial \beta^2} &= - V \cdot \frac{\partial Q^*}{\partial \beta} - \frac{n_U V}{(n_U+1)b_1} V \\ &= - \frac{2n_U V^2}{(n_U+1)b_1}\end{aligned}$$

Returning to equation (A2.1), we now make all necessary substitutions. It is straightforward to show that $\partial^2 \mathcal{W}^{EC}/\partial\beta^2 < 0$, confirming that the welfare generated by the EC is indeed a concave function of β. Specifically, we observe that:

$$\begin{aligned}\frac{\partial^2 \mathcal{W}^{EC}}{\partial \beta^2} &= (1-\epsilon) \cdot \frac{\partial^2 \mathcal{W}^{prod}}{\partial \beta^2} + (1+\epsilon) \cdot \frac{\partial^2 \mathcal{W}^{cons}}{\partial \beta^2} = \\ &= (1-\epsilon) \left\{ \frac{2n_U V^2}{(n_U+1)b_1} - 2 \cdot \left[\frac{n_U V}{(n_U+1)b_1}\right]^2 \right\} - (1+\epsilon)\left[\frac{2n_U V^2}{(n_U+1)b_1}\right] = \\ &= (1-\epsilon-(1+\epsilon)) \cdot \frac{2n_U V^2}{(n_U+1)b_1} - 2 \cdot (1-\epsilon)\left[\frac{n_U V}{(n_U+1)b_1}\right]^2 = \\ &= -2\epsilon \cdot \frac{2n_U V^2}{(n_U+1)b_1} - 2 \cdot (1-\epsilon)\left[\frac{n_U V}{(n_U+1)b_1}\right]^2 < 0.\end{aligned}$$

To complete our proof, we must derive the first-order condition for total welfare maximization and identify the welfare-maximizing value of β. We begin by noting that equation (A2.2) can be rearranged as follows:

$$\begin{aligned}
\frac{\partial \mathcal{W}^{prod}}{\partial \beta} &= VQ^* + \frac{n_U V}{(n_U+1)b_1}(\beta V - b_0 \cdot n - 2b_1 \cdot Q^*) = \\
&= V \cdot Q^* \left(1 - 2b_1 \cdot \frac{n_U}{(n_U+1)b_1}\right) + \frac{n_U V}{(n_U+1)b_1} \cdot (\beta V - b_0 \cdot n) = \\
&= V \cdot Q^* \cdot \left(\frac{1-n_U}{n_U+1}\right) + \frac{n_U V}{(n_U+1)b_1} \cdot (\beta V - b_0 \cdot n) = \\
&= \frac{V \cdot Q^*}{n_U+1} + \frac{n_U V}{(n_U+1)b_1} \cdot \underbrace{(\beta V - b_0 \cdot n - b_1 \cdot Q^*)}_{=\mathcal{W}^{prod}/Q^*}
\end{aligned}$$

Analogously, we can rearrange equation (A2.3) as follows:

$$\begin{aligned}
\frac{\partial \mathcal{W}^{cons}}{\partial \beta} &= -V \cdot Q^* + \frac{n_U V}{(n_U+1)b_1}\left[\underbrace{(1-\beta)V - F}_{\mathcal{W}^{cons}/Q^*}\right] \\
&= -V \cdot Q^* + \frac{n_U V}{(n_U+1)b_1}\frac{\mathcal{W}^{cons}}{Q^*}
\end{aligned}$$

By replacing the final expressions in the last two equation into (A2.1), we conclude that:

$$\begin{aligned}
\frac{\partial \mathcal{W}^{EC}}{\partial \beta} &= (1-\epsilon) \cdot \left[\frac{VQ^*}{n_U+1} + \frac{n_U V}{(n_U+1)b_1} \cdot \frac{\mathcal{W}^{prod}}{Q^*}\right] - (1+\epsilon) \cdot \left[V \cdot Q^* - \frac{n_U V}{(n_U+1)b_1} \cdot \frac{\mathcal{W}^{cons}}{Q^*}\right] = \\
&= \frac{VQ^*}{n_U+1} \cdot (1-\epsilon) - (1+\epsilon) \cdot V \cdot Q^* + \frac{n_U V}{(n_U+1)b_1 \cdot Q^*} \cdot \left[\underbrace{(1-\epsilon)\mathcal{W}^{prod} + (1+\epsilon) \cdot \mathcal{W}^{cons}}_{=\mathcal{W}^{EC}}\right] = \\
&= \frac{VQ^*}{n_U+1} \cdot [1 - \epsilon - (1+\epsilon) \cdot (n_U+1)] + \frac{n_U V}{(n_U+1)b_1 \cdot Q^*} \cdot \mathcal{W}^{EC} = \\
&= -\frac{VQ^*}{n_U+1} \cdot [2\epsilon + (1+\epsilon) \cdot n_U] + \frac{n_U V}{(n_U+1)b_1 \cdot Q^*} \cdot \mathcal{W}^{EC} = \\
&= \frac{n_U V}{(n_U+1)b_1 \cdot Q^*}\left[\mathcal{W}^{EC} - \frac{b_1 \cdot (Q^*)^2}{n_U} \cdot [2\epsilon + (1+\epsilon) \cdot n_U]\right].
\end{aligned}$$

The FOC for total welfare maximization thus requires the expression in square brackets to be zero, leading to the formulation of the optimal share β^* as given in equation (12).

A.3 Proof of Proposition 2

In this appendix we outline the procedure used to prove Proposition 2 in Section 5.3. The proof follows the same steps as those presented in Appendix A.1, which pertains to Proposition 1, with the necessary adjustments to account for the two-stage allocation process whereby net producers first decide the quantities to serve large consumers (with priority), and then allocate the residual supply to small consumers.

We therefore limit ourselves to highlighting the main modifications, specifically showing how some of the key equations are altered relative to the baseline model. We begin by reporting the quantity of energy supplied to large consumers by each producer at the end of the first stage of the allocation process. This quantity corresponds to:

$$q_{i,l}^*(F_l) = \begin{cases} 0 & \text{if } Q_l(F_l) = 0 \\ \frac{Q_{U,l}^D(F_l)}{n_{U,l}(F_l)} & \text{if } Q_l(F_l) \in (0, \overline{Q}_i^D) \\ \bar{k}_i & \text{if } Q_l(F_l) \in [\overline{Q}_i^D, \bar{K}) \end{cases} \tag{A3.1}$$

where $Q_{U,l}^D(F_l)$ denotes the quantity demanded by large consumers and fulfilled by those net producers who are unconstrained in their contribution to the community, as defined in equation (21). Finally, the term $n_{U,l}$ appearing in equation (A3.1) denotes the number of firms that are unconstrained in their provision of energy to large consumers. This can be expressed as

$$n_{U,l}(F_l) = n - n_{C,l} = n - \sum_{i=1}^{n} \mathbb{1}_{\{Q_b(F_b) \geq \bar{\epsilon}_i\}}.$$

At this point, to obtain the result established in Proposition 2, it is sufficient to substitute the following terms into equation (7) from Proposition 1:

- $n_{U,l}$ in place of n;
- $\hat{k}_i$ in place of $\bar{k}_i$.

After performing a few manipulations, the final expression for $q_{i,U,s}^*$ can be obtained.

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