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Decarbonized and inclusive energy: a two-fold strategy for Renewable Energy Communities

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Energy communities and self-consumption structures are receiving significant attention in Europe due to their potential contribution to a sustainable energy transition and the decarbonization process of the energy system. They are considered a powerful instrument to involve end-consumers in active participation in the energy system by becoming self-producers of renewable electricity and increasing their awareness of their potential contribution by adapting their energy behavior to the global or local power system needs. An Energy Community (EC) can also contribute to alleviating energy poverty, which occurs when low incomes and poorly efficient buildings and appliances place a high proportion of energy costs on households. The main driver would be the reduction in energy costs obtained if some members agree to share their surplus electricity at a lower price with vulnerable members. Similarly, a renewable energy community (REC) can facilitate access to energy assets by sharing the investments among the community members and exploiting existing complementarities. For example, vulnerable members could share their roofs with others to install solar panels in exchange for low-cost electricity. RECs can also help vulnerable members by reducing the barriers to accessing subsidies for building efficiency investments thanks to collective community initiatives, easing information dissemination, and helping with bureaucratic processes.

Section 1: Energy communities' benefits and European Union regulatory context

ECs are one of the focuses of the new European Union energy strategy, where Member States (MS) are transposing the EU directives to their national regulations. EC concepts and self-consumption are introduced in the EU regulation by Directives 2018/2001 and 2019/943 related to the internal EU electricity market, and 2019/944 which sets the goals regarding energy use from renewable sources. ECs can be of two main types, REC and citizen energy communities (CECs), and their primary purpose is to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where they operate rather than to generate financial profits. While RECs focus on local community premises and are limited to renewable generation, CECs may engage in generation from renewable and non-renewable sources, and in additional activities such as electricity distribution, supply or aggregation. ECs can also engage in self-consumption, which is a regulated activity to use energy self-generated in an individual self-consumption (ISC) or to share it with other members of a collective self-consumption (CSC).

The following table provide definitions of the main concepts used along this text.

EC	Energy community: a legal person that empower citizens, small businesses, and local authorities to produce, manage and consume their own energy. Can be REC or CEC.

REC	Renewable energy community: a legal entity of members or shareholders that are natural persons, small or medium companies, or local authorities, including municipalities, located in the proximity of the renewable projects it owns and develops, whose main purpose is to provide environmental, economic, or social community benefits for its shareholders or members or the local area where it operates, rather than financial profits. They can produce, consume, store, sell and share renewable energy.
CEC	Citizen energy community: a legal entity of members or shareholders that are natural persons, local authorities, including municipalities, or small enterprises, with primary purpose of providing environmental, economic, or social community benefits to its members or shareholders, or to the local areas where it operates, rather than to generate financial profits. They can produce, store, distribute, share, supply, provide energy efficiency services or charging service for electric vehicles, aggregate and consume energy to its members or shareholders.
ISC	Individual self-consumption: the individual energy activity of producing local renewable generation for self-consumption.
CSC	Collective self-consumption: the collective energy activity of producing local renewable generation for self-consumption and for sharing with those members of the CSC in need of supply.
AC	Allocation coefficients: AC are factors that, multiplied by the net energy locally generated by the members of a collective self-consumption, provide the energy allocated to the CSC members with net consumption.

RECs can be condominiums sharing a common rooftop PV plant, neighborhoods, or villages with one or several PV plants on neighboring lands, or heterogeneous mixtures of nearby consumers, local industries, and private or public services facilities that own and share energy assets, share their electricity surpluses with those REC members in need of supply, and provide common interest energy related projects and procurement. RECs can inform about and provide financing possibilities for distributed energy resources and energy efficiency projects. They can contribute to decarbonization, improve energy behavior patterns that can be taken as reference models to follow, carry out specific diagnostics of energy behaviors and installations, or promote forums to encourage more sustainable energy behaviors and increase energy literacy.

RECs increase awareness among final consumers about, for example, the possibilities of sustainable energy, access to efficient and quality services, to create social cohesion thanks to the sense of community belonging. In fact, consumers engagement can be encouraged by the romantic feeling of bypassing traditional energy suppliers and keeping the money locally in an activity sector traditionally highly concentrated in a small group of large companies, although REC will generally continue to have a dependence with external suppliers. This romantic incentive can also contribute to helping vulnerable consumers by providing them with benefits that traditional suppliers would hardly provide.

The EC´s manager can act as investor, financial intermediary, energy consultant, and project manager, providing assets financing and maintenance services, helping, or facilitating the collective purchase of shared distributed energy resources (PV, insulation of buildings or facilities, batteries) or of more advanced and larger scale resources that would not be viable in the case of individual investments. The REC's manager can also play a relevant role as intermediary and financing supporter in the procurement and maintenance of local energy resources and grids, including resilience services such as island microgrids operation.

REC can raise capital in several ways. The most common is equity participation with REC shares and membership fees or project-specific equity funding. The latter can be captured either from local members interested in owning EC assets or from third parties, including crowdfunding at lower rates from small investors interested in the project's social aspects. The REC can also finance projects through debt, i.e., from third parties not interested in owning shares in the projects, such as bank loans or bonds. Debt crowdfunding is also an option, including by community members who have confidence in the REC projects and aims. Finally, public grants and subsidies for renewable energy and the fight against energy poverty can be provided by the REC to its own projects or to members who would not otherwise have the knowledge or capability to access them.

Perhaps most importantly, RECs can provide CSC services, allowing members that self-generate energy to share it with others who are consuming from the grid. Although self-consumption is a regulated service that does not require a REC to be operated, it is complementary with many of the services REC can provide to their members. For example, members not able to install their own generation assets could benefit from the potential generation of other members. Limitations to installing their own generation may come from a lack of space, financing difficulties, high individual costs due to low returns of scale, insufficient surplus valorization when individually selling back to the public grid, lack of awareness, etc. In this sense, RECs can also be considered as an instrument to help integrate vulnerable and non-vulnerable consumers in CSC by providing or contracting consultancy, financing, and project implementation services, in addition to the management of the CSC itself.

In an REC with CSC, the shared energy must be of renewable origin and must comply with physical or electrical proximity among members, allowing them to benefit from discounts on the grid access tariffs for the energy self-consumed. On the other hand, CECs can share energy of non-renewable origin, and the proximity rules are usually relaxed to facilitate the energy sharing and portfolio optimization of its resources, but discounts on grid access tariffs are generally not applied. However, although this is the approach in the EU directives, transposition to MSs can be different, as in Portugal where CECs require the same proximity criteria as RECs.

CSC is arguably the service that adds most value to RECs business models in the EU, reducing the energy cost of its members. However, in addition to these savings, including the provision of the technical means (such as a management platform) to share and manager the energy surpluses, or the possibility of operating a local energy market (LEM), REC can offer other relevant social services to members and non-members for the mitigation of energy poverty, some of them being:

- Reduced energy costs through energy sharing, energy awareness, behavioral change, and increased household energy efficiency to achieve cost-effective comfort levels.
- Reduction of energy poverty by supporting and integrating local energy-poor households or providing tools to local government initiatives in this regard.
- Benefiting from community assets energy sales, community rooftop lending, and other business opportunities, adding value to REC membership and local business.
- Increased social awareness on climate change and decarbonization issues and a more respectful attitude towards the environment.
- Strengthening local development by reducing the energy costs of local businesses, improving their competitiveness, and mobilizing capital for local investments and jobs, keeping the money within the local community rather than going to suppliers.
- Democratic governance through participatory decisions and freedom to enter or leave are in the governance principles of energy communities, building community relationship, awareness of local energy

issues and urban transformation.

- Generation of local and clean energy contributing to decarbonization and local balancing.

However, as will be discussed below, regulatory constraints, implementation costs or bureaucratic procedures, together with limited economic benefit, may further limit the benefits of CSCs and thus their future development. In addition, proper design of the economic signals that are sent to consumers in terms of electricity price and grid access tariffs, and proper accounting of grid losses, appear to be essential to avoid over-investments in local solar generation, or to balance it with storage systems.

Section 2: New model of the power system under the EU self-consumption paradigm

The activities of self-consumption and distributed flexibility provision are changing the actors' roles in the traditional energy production and supply model. In the traditional EU power sector relational model, shown in Figure 1, we can identify the following main actors:

- **Consumers**, who have an essentially passive role, contract the supply with a supplier on the free retail market or at a regulated tariff (last resort tariff) and consume according to their needs and resources. Consumers' payments for energy supply are made to the suppliers they have contracted, including the cost of the energy supplied and network access charges.
- **Suppliers**, who purchase energy on the wholesale market to meet the expected consumption of their customers' portfolio, are responsible for the deviations they cause in the system when the energy purchased differs from that finally supplied. Suppliers bill their customers for the full costs of supply and pass on the access charges they pay for the use of the networks to their operators (whether distribution networks operators or DSOs, or transmission network operators or TSOs).
- **Producers** sell their energy on the wholesale market to traders and large customers (not shown in Figure 1) with the size to operate directly on these markets.
- The **DSO** is responsible for the physical delivery of energy to the final customer by operating and maintaining the distribution networks and metering the energy delivered.
- The **TSO** is responsible for the physical delivery of energy from the producers connected to the transmission network to the distribution networks of the DSOs by operating and maintaining the transmission network and metering the energy delivered to that grid.

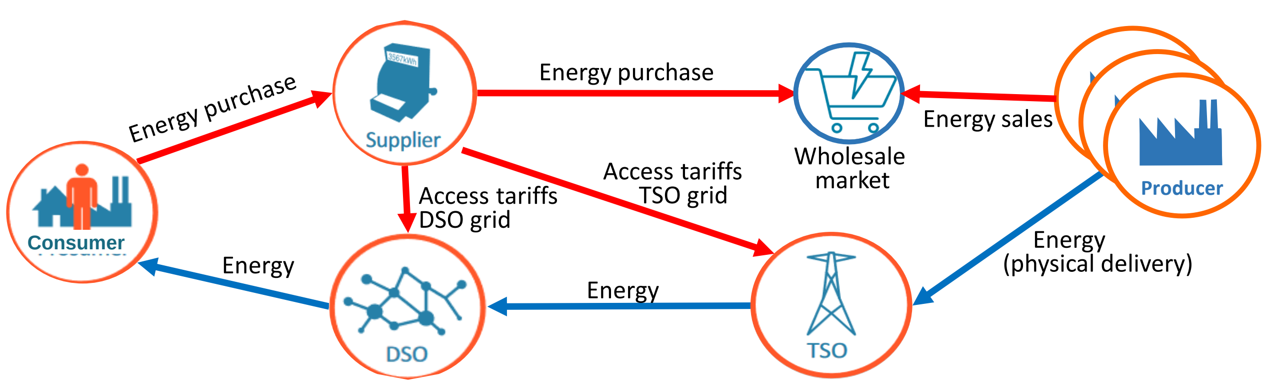

Figure 1: Traditional main actors and relationship model of the power system in the EU context

The decentralization of the energy system and the self-consumption activities are changing the role of these main players and creating space for new ones. Figure 2 represents a first step in this evolution, where the new activities and actors are highlighted with a yellow arrow. Two new actors are added:

- **Prosumers**, with an active energy role, may generate their own energy and manage load and storage systems. They may also share energy locally with other prosumers and provide services to the grid by contracting an Aggregator. According to EU directives, prosumers keep their rights and obligations as consumers, which means they must contract suppliers who are still responsible for procuring their expected supply from the wholesale market. This also means that suppliers are still responsible for the imbalances of their customers due to unexpected changes in their consumption profiles, which can be increased by self-consumption and energy sharing activities. This increased balancing risks impacts the supply costs and may eventually be paid off by prosumers as a service.
- The **aggregators** intermediate prosumers and wholesale agents. They manage prosumers portfolios to buy their energy surpluses and sell them to the wholesale energy markets. In addition to producing, prosumers can, under certain conditions, manage their own consumption profile according to the economic signals they receive, bringing flexibility to the system that is also managed by their aggregator, to be traded in wholesale flexibility markets, prosumers can, whether intraday (where market agents can manage their portfolios to minimize imbalances), TSO's flexibility markets (for overall system balancing or to solve constraints in the transmission network) or DSO's local flexibility markets (to solve constraints in the distribution networks). This is a further step which will be of great importance for the system operation in a context where large gas and coal plants, traditional providers of this flexibility, are being progressively replaced by generation based on renewable sources. Prosumers flexibility adds additional complexity to the roles of the agents and their relationship, as flexibility activations by aggregators affect the imbalance of suppliers in the wholesale market and the operation of the distribution grids, requiring additional TSO-DSO coordination efforts and redefinitions of role responsibility within the rules of the flexibility markets.

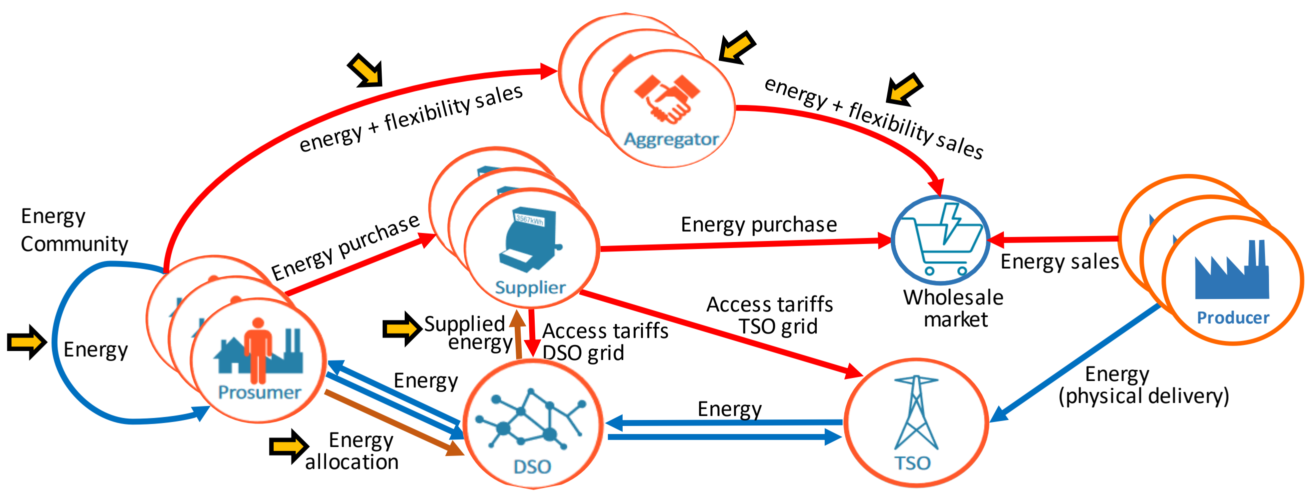

Figure 2: New actors and relationship model of the power system under the EU self-consumption paradigm

As can be guessed from Figure 2, self-consumption also adds responsibilities to DSOs, such as measuring the net consumption or surplus injection of prosumers, applying the defined local energy allocation mechanisms and informing prosumers of the amount of grid access tariffs they have to pay for the self-consumption that used the public grid, suppliers of how much they have left to supply their consumers, and aggregators of how much surplus of their prosumers they have to sell in other markets.

Section 3: Individual and Collective Self-consumption and Energy Communities

In more detail, and as Figure 3.a shows**, individual self-consumption** is a regulated energy activity where a consumer becomes a prosumer (or self-consumer) by installing energy assets and generating part of its own supply E_t^G. Energy assets can be behind-the-meter (BTM), i.e. connected directly to the internal prosumer grid behind the DSO meter, or in front-of-the-meter, connected elsewhere to the distribution grid and with a dedicated DSO meter. The ISC is the simplest self-consumption structure in the EU. As a consumer, the prosumer has a contract with a supplier who supplies him with the necessary energy E_t^{SUP} at the agreed price λ_t^{buy} when his own generation is not sufficient for his consumption, but can also contract an aggregator to sell him his surplus energy E_t^{SUR} at the agreed price λ_t^{sell} if his generation is greater than his consumption.

The ISC regulation defines the rules that apply to this activity and reduces barriers to entry into the electricity market, such as how local generation must be deducted by the DSO from the energy supplied to the prosumer for each interval settlement period (ISP), the direct or indirect access rights provided to sell the surplus energy to the wholesale market, the maximum distance between the resources connected to the grid, or the grid access tariffs λ_t^{grid} applied to self-consumed energy when using the public distribution grid. Indeed, when the prosumer's assets are not BTM, a grid access tariff for the energy self-consumed is typically charged to account for the grid usage. These tariffs are usually reduced to reflect the partial local use of the grid, corresponding to the voltage level where the consumption and generation resources are connected. This justifies, in general, proximity rules to limit the physical or electrical distance between the generation and consumption resources of an ISC. The duration of the ISP differs from one country to another, from one hour to 15 minutes, although there is a general trend in the EU to converge towards 15 minutes, also in wholesale markets.

Collective self-consumption extends ISC activity by allowing prosumers to share their surplus energy with other prosumers in need of supply, before selling it to their aggregator, as shown in Figure 3.b. The CSC regulation defines the rules that apply to this activity, such as the maximum physical or electrical distance between CSC members, the way in which prosumers' surplus can be allocated to other prosumers, how the energy shared is financially accounted for, and the network access tariffs to be paid when sharing energy using the public distribution network. As Figure 3.b shows, CSC members, such as P1, can share their energy surplus with other members consuming, such as P2 an P3. The energy generated by the grid-connected generation facilities belonging to the CSC can also be shared with the CSC member, and the CSC must define its internal rules to compensate the producers or owners of the generation facilities for the energy supplied locally. CSC members have their own opportunity costs, i.e. the supply and surplus prices of buying from or selling to the grid ($\lambda_{i,t}^{buy}$ and $\lambda_{i,t}^{sell}$ for a prosumer i at ISP *t*), since they maintain the right of contracting their own suppliers and aggregators. However, if the final surpluses can be sold individually by the members or collectively by the REC depends on the regulatory framework. For instance, in Portugal the REC's manager must aggregate all surpluses and sell them to the grid, then distribute the revenues among the members according to previously agreed CSC rules.

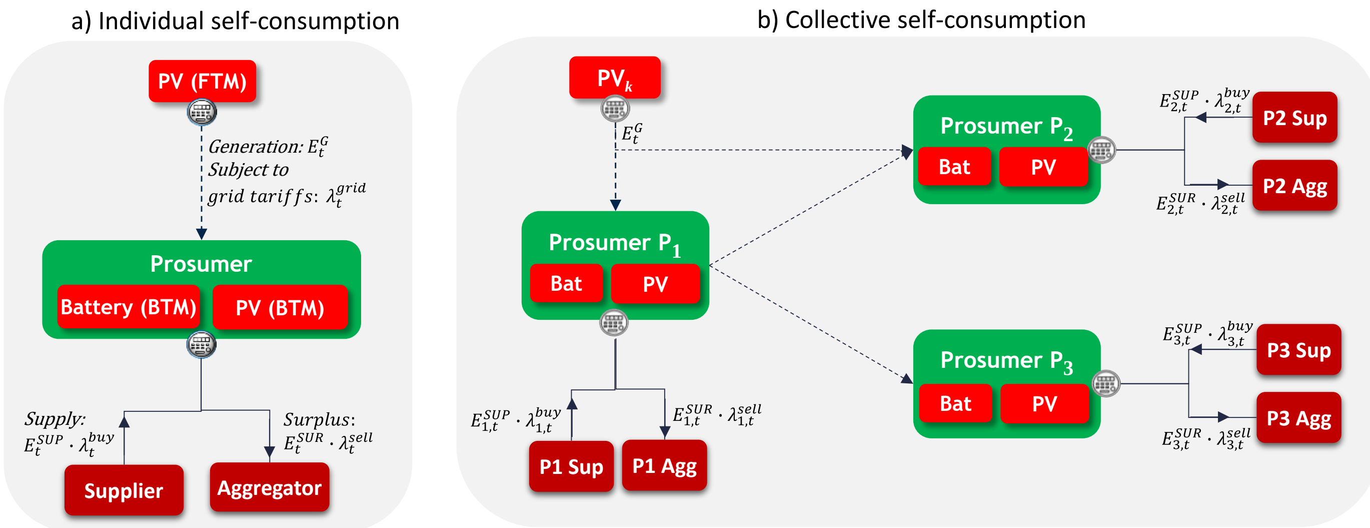

Figure 3: Individual and collective self-consumption.

In RECs with self-consumption, business models vary regarding the objectives of the stakeholders, the way energy is shared and financially compensated among the members, their activity sectors, and their energy behavior. Members with an investor profile may be willing to invest in generation assets to monetize them by saving energy costs and by profiting from the extra revenues obtained by sharing their surplus locally with members with more passive profile, who may want to reduce their energy bill without investing in generation facilities.

The CSC regulation plays a significant role in the feasibility of these business models and how investments in generation resources (such as photovoltaic panels) and flexible resources (such as batteries) can be amortized through energy savings and local energy sharing. In each ISP, when a member with a net energy surplus allocates part of its surplus to a member that is a net consumer, it expects a revenue, either through local transactions or REC compensations to pay for its investments. The consumer, for his part, will be willing to pay for the energy shared up to the price agreed with its supplier. Often, CSC members are willing to accept reduced internal selling prices when sharing with vulnerable community members. Typically, the CSC will need to define internal rules to compensate for these energy allocations. Although simple in concept, the restrictions imposed by regulators on allocation mechanisms may limit the flexibility of business models to be implemented within the CSC, which may also impact the CSC and how vulnerable members can benefit from belonging to the community, as will be explained below.

Subsection 3.1: Energy allocation mechanisms

Energy allocation mechanisms are the rules that define how the individual surpluses of prosumers in the REC are shared. These rules impact not only the total benefit of the CSC to the REC, but also how individual members' benefit. CSC regulations are usually based on the use of allocation coefficients (AC) to compute the energy allocation. They are applied as factors that multiply the locally injected energies to find out how much energy is allocated to the CSC members. This is the case with the regulatory frameworks of Spain, France, Portugal, and some other EU countries. In general, AC should be positive and not add up to more than 1.

Figure 4 shows how individual prosumers engaged in ISCs can benefit from energy sharing when they join to form a CSC, and how different allocation mechanism affect these benefits. The ISC benchmark is given in Figure 4.a where four prosumers behave as separate ISC entities. Producing members (peers P1 and P2, in green) sell their surplus E_n^{SUR} to their contracted aggregator, and consuming members (peers P3 and P4, in brown) buy their consumption E_n^{SUP} from their contracted suppliers. Although P1 and P2 make revenues, the sum of all members' transactions with the grid gives a total net cost C_{tot}^{ind} of 1.55€. In general, the surplus sold to the grid is usually paid at prices substantially below supply. In addition, grid access tariffs for sellers may be lower than for buyers, increasing the buying and selling spread.

As far as the CSC is concerned, there are usually two main types of ACs mechanisms. On the one hand, there are the mechanisms based on **pre-delivery ACs**, whose values must be defined a priori without knowing the energies finally supplied or injected measured in the smart meters of the CSC members. Among the pre-delivery ACs are, for example, the so-called fixed ACs of the Portuguese regulation that can have time discrimination, or the ACs proportional to the contracted power of the Spanish regulation. Fixed ACs are usually defined at the time of CSC creation and are only modified when adding or excluding members. Although they could be estimated to minimize the total energy cost expected by the CSC, since they are defined before metering, they usually lead to non-optimal allocations.

On the other hand, there are those mechanisms based on **post-delivery ACs**, whose computation is done after the measured energies become available to the CSC, which can take advantage of these measurements to optimize the energy allocation. Among them are the so-called proportional to consumption ACs of the Portuguese regulation, which allows sharing the injected energy among the consuming members of the CSC proportionally to their consumption, minimizing the total energy surplus of the CSC. This is the case represented in Figure 4.b, where the proportional ACs provide a total CSC cost C_{tot}^{prop} of 0.44€, compared to the 1.55€ of the ISC of Figure 4.a.

A more flexible mechanism is the post-delivery dynamic ACs, allowed by the Portuguese and French regulations, which can be computed by the CSC manager according to rules that the CSC members have previously agreed upon. Dynamic ACs are much more flexible and allow, for example, to compute an optimal allocation to minimize the total CSC cost according to the opportunity costs of its members. Figure 4.c shows how a set of dynamic ACs allows to reach an even lower final CSC cost C_{tot}^{dyn} of 0.40€, compared to the proportional ACs. In addition, the flexibility of dynamic ACs is essential to reflect the actual internal transactions of a local electricity market, being a prerequisite for their implementation, or to prioritize allocation to specific members, such as owners of collective asset or vulnerable consumers that could benefit from specific rules. However, dynamic ACs are not yet always allowed, as it is the Spanish case, and most CSC regulations don’t seem to incentivize LEM yet, or at least regulate them explicitly.

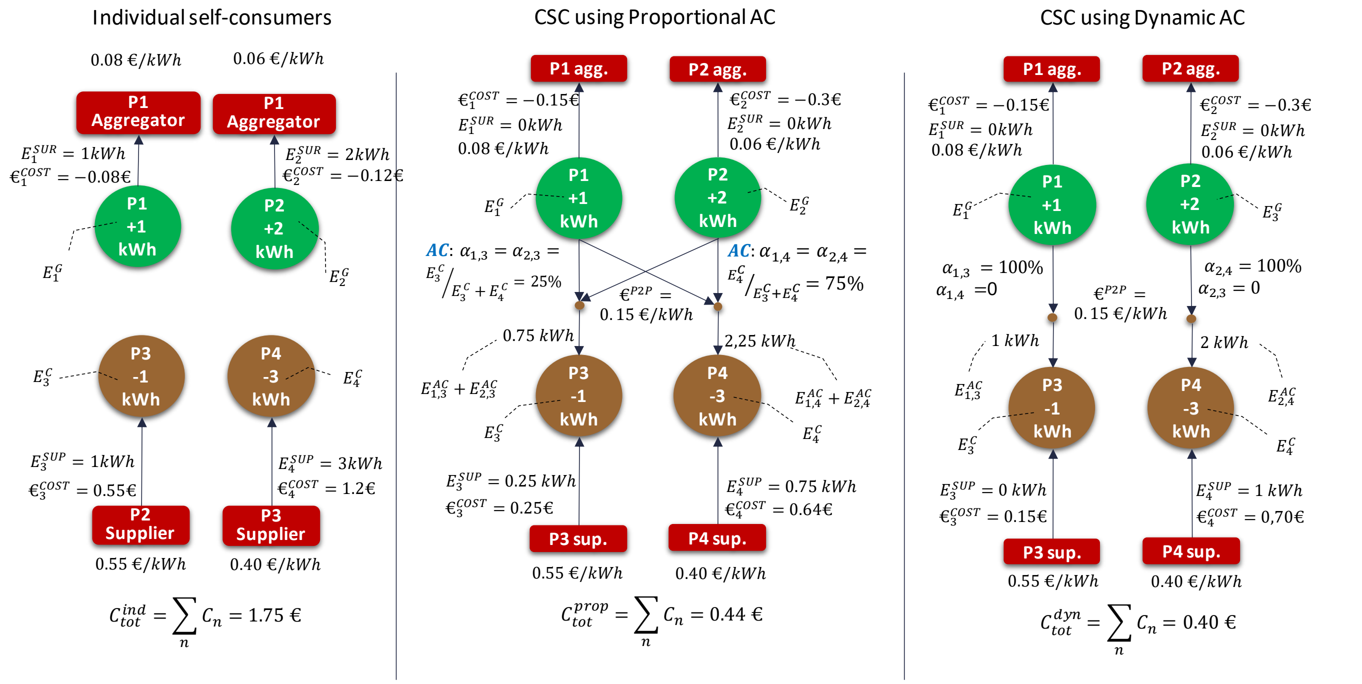

Figure 4: a) ISC; b) CSC with proportional-to-consumption ACs; c) CSC with dynamic ACs

Since consuming members (such as P3 and P4) profit from the surplus of other CSC members (such as P1 and P2), consuming members should compensate financially members with surplus at a local price $€^{P2P}$ that benefits both buyers and sellers, compared to their opportunity costs. Local price computation can be previously agreed on the CSC rules or result from a LEM. In Figure 4, assuming $€^{P2P} = 0.15\,€/kWh$, P3 is allocated more energy when using dynamic AC compared to proportional AC and saves 0.1€, while P4's cost of 0.64€ with the proportional AC increases to 0.70€ in with the dynamic AC, an increment of 0.06€.

The DSO is usually responsible for validating the ACs values and applying them to compute the energy to be allocated among the CSC members and inform their respective suppliers and aggregators. Since these allocation mechanisms determine the energy to be billed by suppliers to their CSC member customers, they modify the supplier's committed position in the wholesale market against which its imbalance is computed. ACs allow a transparent computation of the energy shared among the CSC members, guaranteeing that they are only billed for their net consumption or generation after the energy sharing.

Subsection 3.2: Regulatory discussion

In general, the regulation of CSC addresses several main topics, which are still being developed and tested by the member states, since the current regulation of CSC is still very recent in Europe. In addition to those already covered, we highlight the following.

- **Sharing mechanisms**. ACs are regulated in several MS, either allowing pre-delivery, post-delivery or both methods. Sharing mechanisms can also consider hierarchical rules, as stated in the Portuguese regulation, to allow a lower-level CSC to behave as members of a higher-level CSC. Note also that some MSs sharing mechanisms are not based on ACs. For example, Italy's regulation applies what they call the virtual energy-sharing model. With this model, the energy shared in a CSC is computed by the energy regulator, a state-owned company, as the minimum between total net surplus and net supply of all CSC members, who pays a financial

incentive to the CSC proportional to the energy shared, which predefined the rules to share it among its members.
Sharing mechanisms are the main factor impacting CSC business models, since they define how energy is allocated within the EC, the member's cost savings, and the local energy transactions. In fact, allowing dynamic allocation and dynamic AC is indispensable to implement effective LEMs so that the energy allocated corresponds to the LEM transactions. Effective LEM help to engage end consumers, increasing incentives to invest in local assets. In addition, to benefit vulnerable members with specific allocation rules and reduced prices, also require dynamic AC for its implementation.

- **Proximity rules**. These rules limit, with geographical or electrical distances, how far the members belonging to a CSC can be located. They are often imposed to justify discounts on grid access tariffs for the energy shared using the public grid and may depend on the connection voltage levels of the connected resources. For example, typical maximum distances can range from a few hundred meters up to 20 km, and in some cases or for some voltage levels, the resources may be required to be connected to the same substation.
  From the analysis of some existing regulations, regulations have common ambiguities that should be avoided, such as if the maximum allowed distance is between the most distant CSC members or between the allocation itself from an injecting member to a consuming member.

  Proximity rules, often designed for urban environments, can be a barrier for rural environments, where distances are often much greater and the connected resources are not as abundant, or for isolated communities often closer to energy poverty conditions with difficulties in accessing energy supply. Either different rules are applied to urban and rural environments, or exceptions are allowed where special circumstances warrant.

- **Energy surplus treatment.** Regulations usually define how the energy surplus of the CSC can be compensated. It may impose that it be aggregated and managed by the CSC, as in Portugal, or that it be reallocated among the CSC members to be managed individually, as in Spain. The aggregated management requires selling it to unique aggregator and distribute the benefits among the members that generate them. Although collective negotiation could obtain better conditions, it can reduce the transparency perceived by the CSC members, since they must trust the CSC manager's negotiation with the aggregator and its benefits distribution.
  In addition, it is common practice to define a simplified procedure to sell the surplus to an aggregator of last resort without the need to participate in organized markets that require complex procedures and costly guarantees. Simple but fair mechanisms are essential to add value to the CSC surplus.
  Surplus treatment also communicates with sharing mechanisms. Some AC rules may force injecting members to allocate to other members all the injected energy, preventing them from owning any surplus, or not allow injecting members to allocate more energy than the receiving members consumed, preventing the receiving side from owning the surplus.
  Again, flexibility in the energy surplus treatment may be almost as important as in the energy sharing mechanisms to allow the implementation of innovative business models or to design ad-hoc mechanisms to help vulnerable members.

- **Grid access tariffs.** As mentioned above, it is common practice, in particular for AC-based sharing mechanisms, that self-consumed energy using the public grid pays grid access charges for the grid used (or to be precise, virtually used, as electricity cannot be properly tracked). To incentivize the deployment of CSC structures, additional discounts may be offered on other terms of the grid access tariffs. For example, in Portugal, the regulator reduces the charges related to payments committed to renewable generation plants installed before their full integration into the electricity market.

- **Operation of the distribution grid.** This refers to the possibility of the CSC operating its own (private) grid, which can be useful to save the use of the public grid and the corresponding access tariffs by allocating energy within the CSC's grid premises. However, in some buildings or groups of buildings that are, in practice, a collective grid built by the community, e.g., large flat blocks or shopping centres, prosumers must pay the DSO for all grid services, including their internal energy allocations, even if these grids are managed by local consumers, being a clear regulatory anomaly. Regulating private grids so that communities can benefit from the ownership of the grids and pay the DSO for their actual use of the public grid can also help CSC to reduce consumer costs and provide a level-playing field.

- **Local markets.** LEM seem to be a pending issue in the regulation of self-consumption. Mentioned in EU directives, they often appear laterally in national transpositions but without specific regulation. While excessive regulation could limit the flexibility of these markets, the absence of regulation creates uncertainties about the possibilities for local exchanges and fair compensation and about how taxes should be applied to local revenues. Moreover, while energy communities are natural aggregators that could provide flexibility to third parties, such as the local DSO, generating additional value for their members, regulation of flexibility markets is also an unfinished business. But in any case, it is possible to prove that, providing flexibility while preserving the equilibrium commitments of the BRP involved, may require even more flexible dynamic ACs, such as allowing them negative values or being larger than one.

- **REC vs CEC**. Whereas in the EU regulation, it appears that CEC is a way to manage resources located anywhere in the system, as a tool to develop large-scale aggregators or virtual power plants (VPP) with largely distributed resources, national transposition does not always respect EU principles. VPP provide services to the grid by managing distributed assets in coordination. Limiting the distance also limit aggregators capacity of efficiently operating these assets. This is the case in Portugal, where the same proximity criteria apply to RECs and CECs, against EU directives, where CEC should have no proximity requirements. The limitation of the geographical scope of the CEC seems to be an important constraint for the development of large-scale aggregators balancing of distributed resources as new potential providers of flexibility.

- **Non-renewable resource**. The electricity generated by cogeneration plants, needed in many industrial and agricultural activities, is not of renewable origin and cannot be shared within the CSC of a REC according to regulations. However, this may lead to sub-optimal management of local, flexible resources, such as batteries, which could profit from this local generation to improve the local energy balance. While the alternative could be to create a CEC, where the renewable origin of the energy is not an obligation, this implies giving up the incentives that are normally granted to renewable energy communities, with the corresponding loss of value.

- **Losses**. Losses are not normally addressed in the current CSC regulation. However, if the energy metered at the injection point is fully shared at the consumption points, the actual losses are not considered in the financial settlement. Under the current mechanism, suppliers buy their expected supply increased by a percentage corresponding to the estimated losses, which is passed on to consumers according to their supply and voltage so that losses are roughly socialized among all consumers. If their supply is reduced due to local self-consumption, even if local losses are lower, their contribution to total losses is also reduced, which could increase socialized losses among the rest of the consumers with significant supply. These losses not accounted for will be larger if a significant deployment of CEC with no proximity limitations takes place.

Section 4: Examples of Portuguese REC

Subsection 4.1: Local Citizen-Created REC

In Portugal, some examples of REC are being built using a bottom-up approach. For example, in Telheiras, part of the Lisbon civil parish of Lumiar, with profound socio-economic inequalities, a REC Telheiras is being built by the local citizens, with the support of the local government. Its buildings date from the 80s-90s, suffering from poor construction and thermal discomfort. However, they still use 50% less energy than theoretically required to achieve thermal comfort for both winter and summer.

The starting point was “Viver Telheiras”, a local association that coordinates the Local Partnership of Telheiras, a community network with 24 members created in 2013, bringing together local authorities (Lumiar Parish), institutions (social support), associations (parents, cultural, retired, disabled, residents), organizations (scouts, religious groups), local commerce, and informal groups, to share resources and organize events. Viver Telheiras seeks to contribute to the urban transformation of the Telheiras neighborhood in aspects such as culture, education, active citizenship, social support, and environment. This laid the groundwork for addressing climate change fight and energy poverty. With the collaboration of a very interventive local civil parish, there was a shared vision and mission. With these stakeholders, the will to take essential steps to create the community was easier to handle.

REC Telheiras pilot project is being promoted by Viver Telheiras and the Lumiar Civil Parish, with the support of Coopérnico and CENSE FCT-NOVA in the scope of the EU’s Energy Poverty Advisory Hub first call for technical assistance. REC Telheiras is dealing with all steps to implement the REC, including a feasibility study of the pilot project, considering potential members and the entities identified by the partnership, a financial model to be developed alongside the Lumiar Civil Parish, and the creation of a legal form and governance model that will allow to manage the REC. Moreover, the citizens creating REC Telheiras are developing an inclusive and sustainable REC model, promoting energy democracy, and strengthening the sense of belonging to Telheiras’s neighborhood.

For the development of REC Telheiras, it was necessary to define the context and local framing of the project, explore the workplan in detail, understand and set up the first steps to create the REC from a local association (Viver Telheiras), explore the legal and fiscal aspects of RECs in Portugal, and to explore how to implement, manage, and operate the proposed model. The workplan consists of the main steps to develop a REC, such as defining the pilot energy production/sharing project, who will finance it and how the revenues will be generated, who will be the managing entity that will be owned by the participants in the REC (governance model); how the promoters engage the local community. After the early meetings, the community agreed that the building “Lagar Quinta São Vicente” rooftop would be the most suitable for the PV pilot project of 7-8 kWp. This public building is managed by the Lumiar Civil Parish, a partner in this project. It was also defined that Telheiras’s PV should be managed by “Viver Telheiras”. The PV installation will be invested equally by 14 of the 17 participants of the REC (who also will receive a share of the produced energy). Among the 14 participants is the Lumiar Civil Parish, who is the owner of the rooftop. By investing in the PV installation, the citizens will pay upfront for the energy they will receive by having a reduction in their energy bill. The model addresses energy poverty in the Telheiras neighborhood by including 3 social consumers and investing on their behalf. Part of the investment costs will be covered by the Lumiar Civil Parish, which will also identify and select them according to social criteria. The remaining REC's participants will cover the other social consumer investment costs. The governance model of this REC aimed for democracy and equal rights between all the participants, including those in energy poverty. So, it was decided that every participant should have one equal vote in all the REC decisions.

Regarding the main challenges, they were mainly related to the fact that there are no previous examples of identical projects in Portugal, which means that it was necessary to find how to implement the project in terms of the operational and financing models, navigate the legal and bureaucratic framework and define the relationship between the different partners. Through the development of this REC, it was possible to overcome the challenges faced, even considering that some aspects of the specific context of this REC were new, like defining the sources of financing, understanding how the energy is shared equally by all of the participants (through fixed proportions), and defining the legal form, since from the beginning the partners of this project collaborated very effectively to overcome them.

Respecting the legal format of this REC, this first project will be managed by the local Association. Still, the citizens are discussing the idea of starting an energy cooperative to finance and manage the next production projects in the community.

Subsection 4.2: Innovation Energy Data Spaces for Local Energy Communities

In the context of REC/CEC, data sharing among members and potential members can lead to optimized planning and operation of REC/CEC, unlocking socio-economic benefits and stimulating energy inclusion. The EU Data Governance Act introduced the concept of *Data Cooperatives* to "strengthen the position of individuals in making informed choices before consenting to data use" and the *Common European Data Space* concept that consists of an infrastructure supported by common governance, organizational, regulatory, and technical mechanisms, facilitating access to data and the development of data-centric business models. The main goal is to remove barriers to data sharing, such as interoperability, trust, and privacy/confidentiality, while keeping sovereignty and full control of data.

To advance the development and validation of energy data sharing use cases in real-world settings, alongside the design of citizen-centric digital services and technologies at the local community level, INESC TEC partnered with Cooperativa Eléctrica do Vale d'Este, an energy cooperative acting as a local DSO and retailer. Together, they deployed a comprehensive range of monitoring equipment including total and individual energy meters, smart plugs, ambient temperature, and humidity sensors across 20 households (first wave of early adopters) with PV, electric vehicles, heat pumps, electrical water heaters, among others. The unique feature of this initiative is the use of Data Space technology, particularly the open-source Data Space building blocks developed within the EU-funded project ENERSHARE, *European Energy Services framework enabling data sharing-driven Across- and beyond-Energy Services*. In this community setting, these tools facilitate a wide array of energy and cross-sector services, fostering innovative consumer and community-centric business models. Furthermore, they ensure critical principles such as privacy, confidentiality, cybersecurity, sovereignty, and granting users full control over their data.

On the top of this data sharing infrastructure, the first use case under demonstration is the instantiation (sizing) of REC and simulation of business models. The goal is to optimize, in the planning phase, the capacity of the DER and simulate their operation to estimate an internal reference price to study different business models. For this purpose, combining data from different consumers (i.e., shared by different data owners) is fundamental since it enables the computation of the benefits of belonging to the community and the study of different asset-sharing business models in advance. The data obtained from this REC instantiation can be shared with organizations working to mitigate energy poverty, allowing for a more informed financial assessment of the participation of vulnerable consumers in the REC. For instance, vulnerable consumers can participate in programs where they trade their available space for installing PV panels or battery storage solutions. This can be done through ownership shares in certain assets, reduced energy prices, or by providing non-energy services such as cleaning and inspecting PV panels and maintaining and repairing electrical installations.

During the operation of the REC, another use case is to compute sustainability indicators, such as the traceability of green energy supply within the community or create "happy hours" for community EV charging. Data sharing can also foster the development of circular business models in communities, which are particularly appealing in agricultural settings characterized by seasonal activity. For instance, a surplus of RES can be exchanged for other products/services through barter exchanges, including water, PV panel cleaning, training programs, raw materials, and biofuels. The availability of historical and/or operational data from diverse controllable loads also holds significant value in quantifying their flexibility potential. Access to such data enables consumers to unlock additional revenue streams by exploiting flexibility.

Figure 5 depicts the Data Space components used, namely the TNO Security Gateway (TSG) data connector, identity provider (DAPS in the figure), metadata broker, and a set of negotiation and access policies contracts for data. Additionally, it presents interactions among actors within the energy and data value chains, complemented by information of exchanged data.

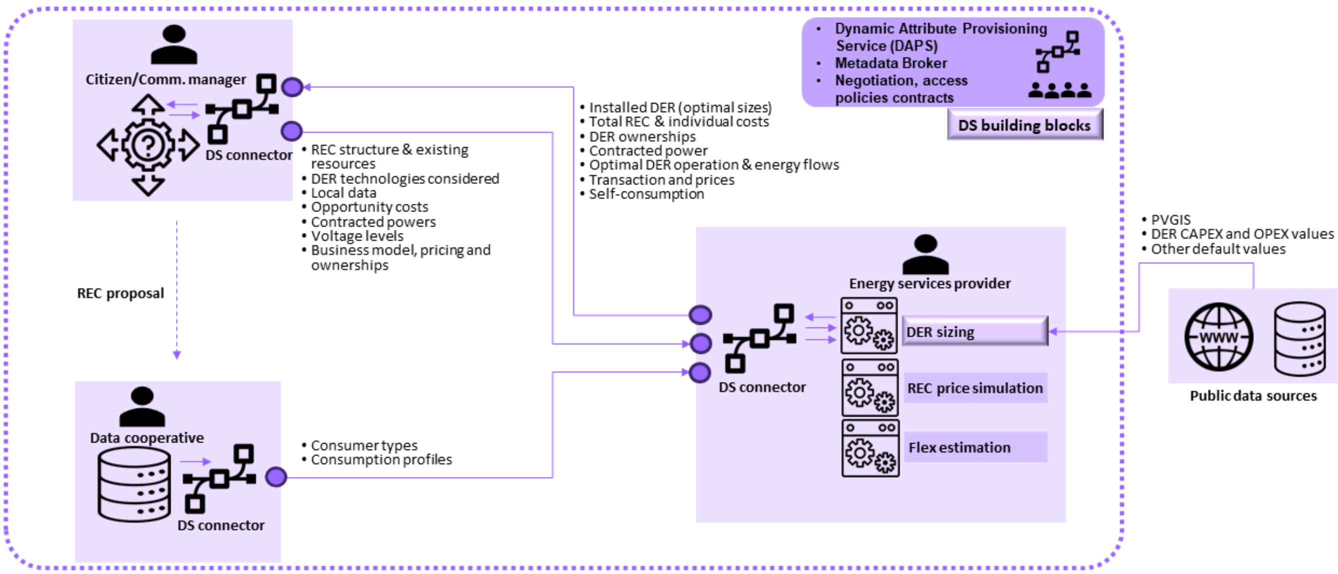

Figure 5: REC use cases augmented by data sharing and Energy Data Space technologies

Such digital infrastructure for data sharing can also boost energy efficiency actions at the community level, particularly for vulnerable consumers. For instance, it can enable building large datasets by combining small chunks of data (e.g., energy efficiency actions and effects) and increase data volume to enable the application of modern machine learning methods, for instance, to quantify/classify the impact of appliance retrofit or renovation actions in advance. This mitigates investment risks and facilitates the improved design of financial support schemes and policies. The cross-consumer data exchange can also help to build training and education programs for energy efficiency. Another use case is to quantify and predict the energy poverty risk by combining socio-economic data with multiple energy consumption patterns. This information can be used to design targeted assistance programs, such as subsidies, energy efficiency upgrades, or financial guidance.

The scope, data volume, and diversity of use cases within the data sharing community are expanding via involvement in additional EU-funded projects like ENPOWER and HEDGE-IoT. These efforts exploit on emerging concepts such as data semantic interoperability, aiming to enhance data use across various services that have a tangible impact at the local level.

Section 5: Challenges to the widespread REC

Regulatory, and administrative improvements are needed to achieve the full potential of CSC, especially considering the mindset transformation towards a distributed renewable energy sector. Based on our experience in implementing CSC projects and performing related scientific research, we believe useful to highlight several obstacles to REC widespread:

- **Pace of regulatory transition.** EU directives state that grid operators and regulators must facilitate the procedures required to connect self-consumption assets to the grid subject to their reduced scale and impacts on the local grid. However, DSOs, which are responsible for many of the technical processes that enable the development of CSC, can be slow and very often reluctant to changes, creating barriers that slow down CSC expansion. Although regulated since 2019, some member states DSOs are still implementing AC in their settlement procedures, and dynamic AC is often ignored or significantly delayed. In addition, a fully deployed smart meter infrastructure is needed to have energy measurements for every ISP to compute the energy allocated internally and supplied by the suppliers. However, this is still an ongoing process in some countries, such as in Germany, where smart meter deployment is in a very preliminary phase. Also note that in the absence of smart meters, suppliers' imbalances are usually calculated according to standard consumption profiles provided by regulators. This generates systematic imbalances at the wholesale level, as suppliers purchase energy according to these standard profiles independently of the actual consumption of their customer portfolio. Therefore, resolving the interactions of the suppliers' positions in wholesale markets with the AC mechanism, in the absence of smart meters and accurate suppliers' imbalances computation, is of little value.
- **Procedures adapted to small scale agents.** Simplified procedures to reduce barriers to entry in the electricity markets should be developed by Member States, including websites to centralize the interfaces used by final consumers to create ISC, CSC, and ECs and to interact with the involved actors such as suppliers, DSOs and the administrative bodies in charge of licensing the CSC or the EC. This is a fundamental step towards reducing the challenges for small-scale self-consumers to participate in the complex electricity sector. However, some countries are still struggling to review these procedures and create an easy-to-work environment for new self-consumers. Regulation often enforces the development of such digital websites and platforms, but this adds new administration services, which require increased economic and human resources for their development and operationalization. For instance, complaints about the existing bureaucracies, the complexity of the licensing processes, and the slowness in processing licensing requests are common.
- **CSC untied to EC.** During the recent regulatory EU market reform, it was proposed in public consultation the possibility of guaranteeing the consumers the right to share energy directly with other consumers, without creating formal energy communities, to further empower them and engage them in the energy system. This proposal meant to untie the CSC activity from formal REC structures, giving more freedom to final consumers to find beneficial business models. Although this was dropped in the final directive, it reflects two important aspects. Firstly, CSC is seen by the EU as a relevant driver for decarbonization and energy independence, and secondly, there is a need to simplify the energy-sharing mechanisms to promote energy-sharing activities among final consumers. In this sense, there is a joint challenge involving regulators, DSOs, and technology providers to facilitate the development of low-cost REC's management tools, especially in disadvantaged areas or considering the limited benefits that CSC can have in the short term compared to ISC.
- **Mindset transformation**. CSC definitions and rules may also limit the scope of business models and services that REC can provide to final consumers. Post-delivery allocation mechanisms should be not only widely accepted but also subject to more flexible rules, and the integration of CSC and LEM should be explicitly considered by

regulators. Instead, there are widespread rules in Member States regulations limiting the participation of for-profit entities and restricting the investments in generation assets to capacities like the individual prosumer's expected load. This follows a mindset where CSC is still merely a way to share the prosumer's mismatches of generation and consumption. However, a full integration of consumers into the electricity markets could be achieved using the CSC regulation to boost LEM. This would help to increase distributed renewable generation and cost-efficient local balancing, contribute to decarbonization while bringing new competition to the traditional electricity retail market and reduce final consumer costs.

This can be done without cross-subsidies and under fair conditions regarding the wholesale markets if grid access tariffs adequately cover distributed and centralized contributions to the grid costs. In this sense, several aspects can become highly relevant with the expansion of CSC. On the one hand, grid access tariffs must be appropriately reviewed to guarantee that the grid costs are properly recovered, reflecting the grid usage and the need to support the grid infrastructure to ensure supply, probably with fixed charges. On the other side, CSC regulations do not consider grid losses, so the energy measured at the injection point is the energy that can be allocated to the consumption points. While the wholesale market regulation states that suppliers must buy the energy they supply, adding the estimated grid losses, the fact that CSC regulation does not consider losses means that traditional consumers paying losses are implicitly assuming self-consumers losses. This tariffs revision considering locational aspects and grid losses criteria could also help to free CSC from the current strict distance limitations, which reduces the potential members of REC, especially in less populated areas.

Finally, an adequate design of the integral tariffs applied to consumers, which adequately reflect the price of electricity price and the use of the grid, accounting for network losses, seems to be essential to avoid over-investments in local solar generation or balance it with storage systems.

- **Non-renewable self-consumption**. Finally, some MSs regulate CSC and REC together, which implies that self-consumption is often required to be renewable. While desirable, there are cases where small businesses inside cities generate energy from non-renewable but efficient industrial processes, as is the case with cogeneration plants. However, they are not allowed to join CSC schemes since the energy is not renewable, missing the opportunity to optimize its operation by sharing their surplus with the local community.
- **Data sharing tools**. As discussed in the real-world example of a Data Space energy community, data sharing holds the potential to optimize the planning and operation of RECs, yielding significant local socio-economic benefits. However, designing effective economic and non-economic incentives for sustained data sharing at the business-to-client level is fundamental, requiring an interdisciplinary approach that integrates insights from social sciences and humanities. From a technical standpoint, two critical challenges emerge: firstly, ensuring the preservation of data privacy and sovereignty across multiple data-centric use cases, which may require the edge and/or federated artificial intelligence-based methodologies; secondly, there is a need to promote data semantic interoperability, which provides meaning to raw data and aids more automation.

Further Readings

- EU Regulation, directives 2018/2001 (Directive - 2018/2001 - EN - EUR-Lex (europa.eu)) and 2019/943 (Regulation - 2019/943 - EN - EUR-Lex (europa.eu)), and Member State examples of transpositions, such for Portugal, regulations DL15/2022 (Decreto-Lei n.º 15/2022 | DR (diariodarepublica.pt)) and regulation 2/2023 (Regulamento n.º 815/2023 | DR (diariodarepublica.pt)), or France (Code de l'énergie - Légifrance (legifrance.gouv.fr))

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