# Better Together: Harnessing Social Relationships in Smart Energy Communities

**Abstract**
Social relationships can influence individual behaviours and personal choices, foster cooperation, and build solidarity. In this Perspective, we argue that harnessing social relationships connecting people living in the same community can help improve the functioning of smart local energy systems and facilitate cooperation towards shared objectives. These shared objectives could include reducing energy poverty, investing in clean technologies, and fostering energy justice. Therefore, we propose the new concept of smart energy neighbourhoods, which we define as a local energy system sharing (i) the same local energy infrastructure, (ii) a network of social relationships and group-focused concerns, and (iii) smart adaptive mechanisms enabling participation, coordination and cooperation. The paper discusses the beneficial role that smart energy neighbourhoods could play within future energy systems, their possible design, and key challenges for their implementation.

**Keywords**: local energy system; social relationship; collective human behaviour; smart energy neighbourhood; cooperation; shared objective; energy community.

## 1. Introduction

Social relationships can have a significant impact on people's lives and their personal choices. People do not live in isolation from one another, and their personal preferences are not immune to external influences [1]. This means that people's behaviours are not only determined by their own inner preferences, but are also affected by their relationships with others, i.e. people's lives are *linked* [2]. The concept of linked lives emphasises the *interdependency* between people, and how behaviours of e.g. family, friends, and communities can affect and steer someone's personal choices [3].

An important consequence of social networks is the potential for people within them to act as a group to *pursue shared goals by means of collective action* [4]. An example is the role that social relationships play in mobilising support for people in need [5], as shown during the recent pandemic, where both social motivators and networks mobilised volunteering activities and citizen-to-citizen support [6].

In this Perspective, we will focus on how local energy systems could be enhanced by accounting for the existence of social networks, and the willingness of groups to act cooperatively towards shared objectives. This could help achieve public policy objectives, such as reducing energy poverty [7] (which is the lack of a sufficient amount of energy for primary human activities), as well as promoting the adoption of climate change mitigation measures at the local level. Networks of social relationships could also be leveraged to stimulate local communities to adopt cleaner technologies [8], and trigger collective actions, such as cooperative green investments, and philanthropic energy donations for people in need [9]. However, this requires the development of new mechanisms that can explicitly incorporate networks of social relationships and members' willingness-to-cooperate towards shared goals into energy system design.

Despite the impact that social relations may have on people's behaviours, and the increasing need for collective action towards energy policy objectives, current energy systems still largely neglect the presence of social relationships between individuals. By contrast, we argue that significant further value could be unlocked from local energy systems by accounting for the networks of social relationships and shared objectives that connect people within local neighbourhoods. These *shared objectives* could include supporting vulnerable people and distressed businesses, improving the local environment, and investing in community energy projects, which could contribute to local prosperity and net zero emission targets. Therefore, we propose the concept of a *smart energy neighbourhood*, which we define as a local energy system sharing:

i. the same energy distribution infrastructure,
ii. a network of social relationships and group-focused concerns, and
iii. smart adaptive mechanisms enabling participation, coordination and cooperation.

This creates new opportunities to improve how energy systems are planned, designed and managed. In turn, smart energy neighbourhood platforms that enable this coordination could offer new tools for fostering cooperation towards objectives shared by members living in local areas, which may also contribute to national policy goals. Figure 1 presents a high-level block diagram of a smart energy neighbourhood.

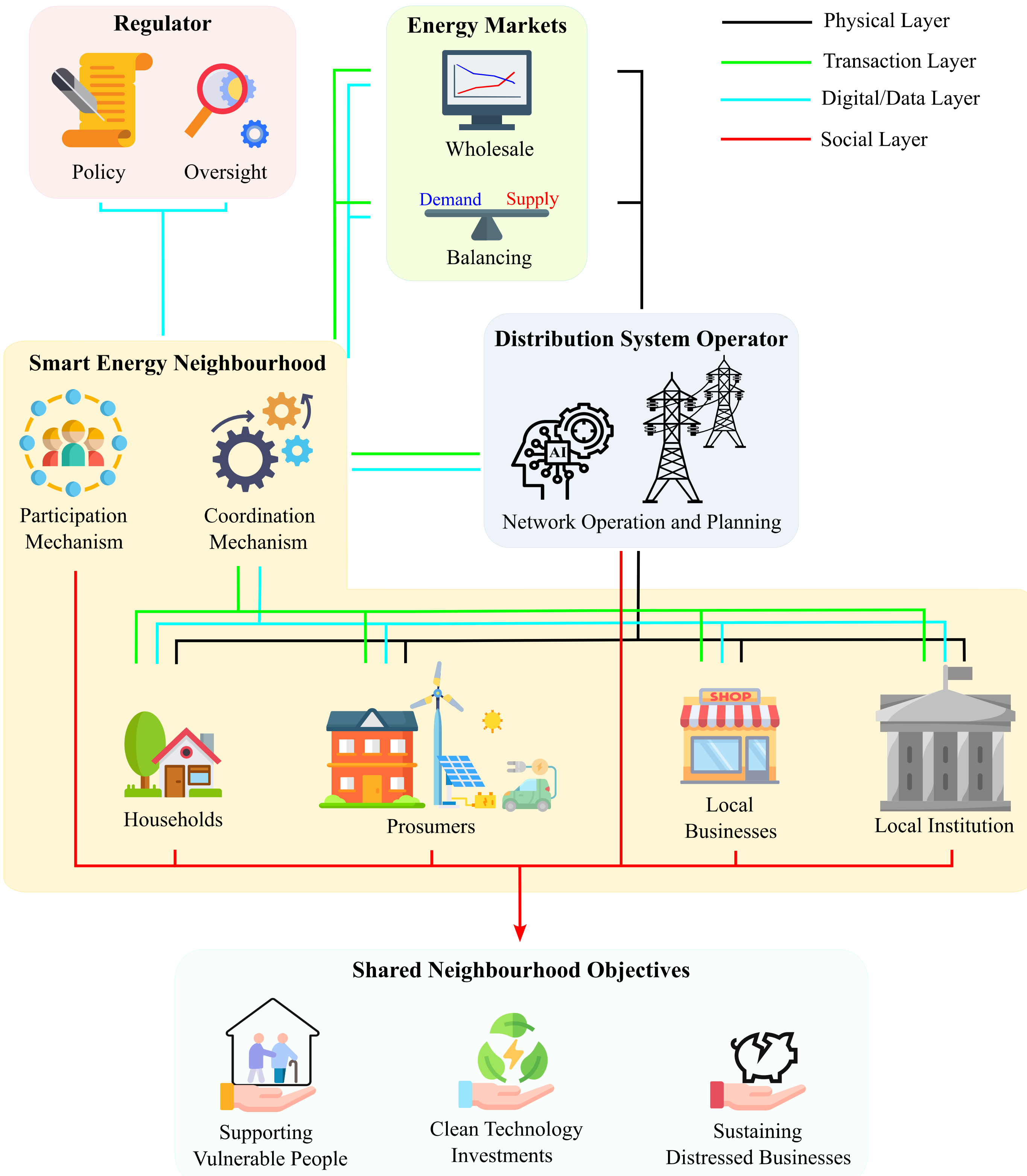


Figure 1: The figure outlines and contextualises the smart energy neighbourhood concept. Members of a smart energy neighbourhood can be households, prosumers (i.e. individuals who consume and produce energy [10]), local businesses, and institutions. Through smart coordination and participation mechanisms, these members can cooperate to achieve objectives that they share for their local area. Shared objectives could include supporting vulnerable people and distressed

businesses, as well as promoting investments in clean energy technologies. A smart energy neighbourhood interfaces with other entities. These include regulators that define policies and perform oversight activities, as well as energy markets that enable trading and service provision. A distribution network operator plans and operates distribution assets. These activities can be enhanced by interfacing with smart energy neighbourhoods to incorporate social motivators into system design. The system operator can also participate in pursuing shared objectives e.g. through joint investments. The physical layer (black lines) represents energy infrastructure e.g. electrical cables [11], gas pipes, and heating systems. The transaction layer (green lines) represents monetary flows between actors, whereas the digital/data layer (blue lines) represents information and communications technology infrastructure.

## 2. How smart energy neighbourhoods differ from other schemes

Smart energy neighbourhoods extend the concept of smart local energy systems by recognising the pivotal role of the *social layer* that connects energy users in the same local area, in addition to physical [12], transactional [13], and digital [14] layers. It is increasingly feasible to understand and coordinate the interactions between these interconnecting layers thanks to the availability of new technologies, including advances in artificial intelligence, low-cost local sensors, high-speed communications, digital platforms, and the internet of things [15]. These tools and technologies allow complex human behaviours to be better captured and modelled [16], which in turn can enable social motivators to be incorporated into how energy systems are operated and designed. Smart energy neighbourhoods extend the role and functionality of smart local energy systems by explicitly accounting for human behaviours and how these are connected and affected by networks of social relationships, with the potential of triggering collective actions towards shared objectives.

A smart energy neighbourhood is an energy system architecture which fits within the broader area of community energy [17]. However, a fundamental element characterizing a smart energy neighbourhood is the explicit recognition of the existence of social relationships among participants in its design. By recognizing this, a smart energy neighbourhood aims at harnessing these social relationships to help improve the functioning of smart local energy systems and facilitate cooperation towards shared objective.

For these reasons, a smart energy neighbourhood can be regarded as a complex system allowing technical, economic and social layers to interact and influence each other. A key consequence of this is that the operating mechanisms of smart energy neighbourhoods can adapt and evolve to better handle both technical challenges (e.g. uncertainty in energy patterns [18]) and social challenges (e.g. reducing energy poverty [19]). In particular, these mechanisms can *adapt* in response to both new social needs that may rise between local members as well as new technical requirements, and can *evolve* (e.g. providing new offerings and commercial products) to incentivise greater cooperation within local areas. This could trigger a virtuous cycle, where new members are attracted and participation increases, expanding the opportunities for cooperation.

The European Union has recently introduced the concept of citizen energy community [20]. A smart energy neighbourhood can fit within the broad legal framework offered by citizens energy communities, but it also provides a more specific architecture which considers the potential for interactions between the social, technical, economic and digital layers to create additional value.

The concept of smart energy neighbourhood extends local energy systems by placing human behaviours and social networks affecting them at the centre of their design. To summarise, a smart energy neighbourhood can be regarded as a *complex local energy system* driven by *adaptive* and *evolving mechanisms,* accounting for *human interactions,* aiming at better handling both *technical* and *social challenges*.

## 3. What value can smart energy neighbourhoods offer

The importance of considering networks of social relationships in the design of local energy systems relies on the potential of *enabling cooperation* among people to pursue shared objectives. These shared objectives could include economic, environmental, and social goals, such as supporting vulnerable people and distressed businesses, promoting shared investments in clean energy technologies, as well as enhancing energy justice [21] in terms of both fairness in cost allocation and participative decision-making processes. Example forms of cooperation include local energy projects with community and energy providers, philanthropic support, and incorporating inequality measures (such as income and energy poverty) into how energy systems are operated and costs are allocated among members. Table 1 presents a broader range of examples of potential shared objectives that could be pursued within smart energy neighbourhoods by enabling cooperation among members and providing new mechanisms for participation and coordination through digital platforms.

Table 1: Example shared neighbourhood objectives

| Economic | Environmental | Social |
|---|---|---|
| • Supporting vulnerable and disadvantaged people [22].<br>• Fostering equitable growth [23] and job creation [24].<br>• Reducing energy poverty [25] and socio-economic disparities [26].<br>• Unlocking shared investment and crowd funding [27].<br>• Promoting fairness in benefit and burdens sharing [28]. | • Fostering local net zero carbon initiatives [29].<br>• Supporting shared investments in clean energy technologies at the neighbourhood level [30].<br>• Improving air quality and reducing pollutant emissions [31]. | • Matching energy projects to community needs to increase acceptability [32].<br>• Promoting energy education [33] e.g. to raise awareness of the benefits of using efficient and clean energy technologies.<br>• Increasing participation in decision making-processes [34]. |

Smart energy neighbourhoods could stimulate the pursuit of shared objectives through cooperative projects and activities that may not otherwise be possible under individual focused schemes and private interests, due to e.g. the scale of the project, perceived risks, or a lack of coordination and information [35]. For example, smart energy neighbourhoods could facilitate cooperative investments and crowd funding [36], as well as joint flexible resource investments between the distribution network operator and members of a smart energy neighbourhood to deploy low-carbon technologies at the distribution level, leading to co-creation of value [37]. There is also a broader opportunity to enhance long-term network infrastructure planning by explicitly integrating shared neighbourhood objectives, and the willingness of members to act cooperatively, into network design. Distribution system operators could prioritise infrastructure that enables the development of energy projects valued by the community, leading to partnerships between distribution system operators, energy retailers, and local community organisations, which could involve cross-sectoral participation and multi-vector energy coordination [38]. Furthermore, acknowledging the importance social motivators and incorporating them into the developed solutions may offer an opportunity to better predict consumer energy behaviours, and thereby improve distribution system operation and planning.

Local members may also be more engaged and responsive to community needs when these affect their local area. Therefore, smart energy neighbourhoods could enhance the impact of government spending associated with energy policy initiatives if these are aligned with neighbourhood objectives [39]. For example, this could accelerate the adoption of climate change mitigation measures, such as subsidies for clean energy technologies, as well as increase the acceptance of new energy projects [40], such as the deployment of wind or solar farms in the local area. In addition, policy makers could use smart energy neighbourhoods to raise awareness of specific initiatives [41], encourage citizen-led participation [42], and incentivise members to cooperate towards shared goals in line with national policy objectives (e.g. through some form of “norm nudging” [43]).

In addition, smart energy neighbourhoods can agree on, contribute to, and track progress towards specific sustainability goals (e.g. reducing carbon emissions, diminishing particulate emissions to improve air quality, increasing energy efficiency). This may also increase visibility of community action, which could increase other people’s willingness to contribute. More broadly, smart energy neighbourhoods can contribute towards a sustainable development by positively affecting (i) the environment, e.g. through the deployment of clean technologies; (ii) the economy, increasing local business investments and fostering job creation, and (iii) the society, involving citizens in their decision-making processes [44]. Other positive effects may occur as a consequence of deferred or avoided investments (both plants and networks), which can reduce e.g. land use.

Further benefits may arise as social relationships may help increase the resilience and facilitate the recovery of smart energy neighbourhoods e.g. after extreme events and natural disasters, where community actions are central in responding to impact and shaping recovery [45].

Finally, new offerings and commercial products could be developed to increase the willingness to cooperate in the pursuit of shared objectives, and to maximize the value of cooperation. Local governments, consumers, energy suppliers, and distribution system operators could all benefit from the development of these offerings and products, as these could help achieve objectives valued by communities, and create new business opportunities for the industrial sector.

## 4. Social relationships in local energy systems

Recently, Hargreaves and Middlemiss [46] demonstrated that individual energy demand can be influenced by at least three types of social relationships. The first type refers to relationships established within the innermost circle of a person’s social network, which includes relatives and friends (e.g. partners, housemates, as well as co-workers [47]). The second type includes relations between the local community and commercial actors (e.g. energy suppliers), and the third type refers to relations of identity in terms of race, gender, age, ethnicity, and disabilities. These social relations influence individual behaviours through a set of daily habits and practices [48] that voluntarily or involuntarily shape individual energy use, and can affect the adoption of clean energy technologies. At the same time, these habits and practices can also be influenced by feedback mechanisms induced for example by smart home appliances or peers, which can trigger virtuous cycles, e.g. in terms of energy savings [49]. Along this line, Jain, et al. [50] reported that occupants in residential buildings who were informed of energy-consumption patterns of peers took different actions than those only receiving data about their personal consumption. This shows that the interactions between members in a local area are not only driven by technical and economic aspects, but also by social relations between them, which may trigger additional feedback mechanisms.

The range of potential social relations is large, spanning from intimate relations to community and class identity. If considered and supported, these social relations may induce members to act towards shared objectives for their neighbourhood, i.e. they can generate, or strengthen, the *willingness to cooperate* to achieve common goals that people perceive as valuable for their local area [51], and foster members’ participation in shared energy projects. For example, a choice experiment conducted in Germany among electricity consumers showed a substantial willingness to pay for renewable energy, transparent pricing, participation in decision-making, and a preference for local suppliers [52].

The preference for local suppliers suggests that members in a local community could be willing to support local businesses provided that appropriate instruments are presents. Moreover, new communication channels, such as social media [53], can facilitate the creation of new social relationships, fostering coordination and bolstering the willingness to cooperatively pursue shared objectives.

## 5. How smart energy neighbourhoods can be designed

The design of smart energy neighbourhoods involves at least two key mechanisms, which can be termed the *participation* and *coordination* mechanisms:

- The participation mechanism ensures the representation and participation of local members (e.g. households, local businesses and organisations) in the decision making processes of a smart energy neighbourhood. In particular, it determines the collective social will, i.e. "what" activities and objectives will be pursued by the smart energy neighbourhood;
- The coordination mechanism consists of processes used to achieve the desired objectives, i.e. it addresses "how" the selected objectives will be achieved.

The pursuit of shared objectives requires a collective effort. Ensuring that processes and outcomes of smart energy neighbourhoods are considered to be *just* is important for participation. An energy system is considered just if (i) both benefits and burdens of energy services are shared fairly between its members, and (ii) members can participate in decision-making processes in a fair and non-discriminatory way [54].

The first requirement is also referred to as *distributive justice*, and the second as *procedural justice* [55]. Benefits include the capacity to actually access the services offered (e.g. affordable energy), whereas burdens refer to costs, risks, and externalities associated with the energy system. Involvement in decision-making processes requires participatory governance, transparency, and data availability to enable informed consent. A third aspect to consider is *recognition justice* [56], which requires recognising the different needs of all groups involved in an energy system. For example, in the context of energy poverty this means recognising that elderly and infirm people may require higher than average room temperature to achieve an equal minimum level of wellbeing [57].

The implementation of just smart energy neighbourhoods requires the design of appropriate participatory decision-making processes and a fair coordination mechanism for benefit and cost allocation, while recognising the importance of different members' needs. This can be achieved by enabling bottom-up participation in governance, where local members (e.g. households, local businesses, distribution companies, and local institutions) can determine operating principles and shared objectives that they perceive as valuable for their local area. Moreover, inequality measures [58], such as income and the level of energy poverty, can be directly incorporated into coordination mechanisms. This bottom-up citizen-driven approach could lead to the development of energy-just platforms, which could enhance consumers' engagement, welfare, and trust, increasing projects' acceptance, and fostering further investments.

## 6. Challenges and future research directions

The development of smart energy neighbourhoods poses several challenges. The willingness to cooperate towards a specific shared objective may differ significantly from one member to another, and from one neighbourhood to another. In particular, the inclination of each community participant towards specific goals (e.g. energy donations to impoverished people) may vary significantly depending on factors such as their trust in local institutions [59], social norms, cultural aspects, individual preferences, and their social network [60]. Therefore, the willingness-to-cooperate and inclination of participants towards different goals should be accurately estimated and modelled.

Different designs (e.g. participation mechanisms) or objectives (e.g. joint public-private network investments) may be more feasible in some socio-economic or juridical contexts than in others [17]. Therefore, the drivers underpinning these differences should be identified, as this could help predict if smart energy neighbourhoods with a particular design, or pursuing specific objectives, could be successfully deployed in different context, such as rural/urban areas or developing/developed regions [61].

Coordination mechanisms need to account for competition due to individual objectives, as well as the potential for cooperation towards shared objectives. The mechanisms should ensure that no individual is penalised by joining the smart energy neighbourhood, and that participants cannot profit by leaving and forming a smaller group (coalition) [62]. This requirement is termed coalition stability [63], and is an important property for cooperative schemes if they are to be long-lasting. Notice also that inequality in resource endowments and loss or benefit heterogeneity may reduce people's propensity to cooperate [64], [65], which may hamper the ability of smart energy neighbourhoods to successfully achieve shared objectives. This effect may be more significant for some shared goals than others, and should be carefully assessed and considered when designing smart energy neighbourhoods. However, data visibility and transparent allocation mechanisms supported by smart energy neighbourhoods could help address some of these challenges. Coordination mechanisms should also be computationally tractable and scalable, as the number of people involved could increase significantly in densely populated urban areas. Analytic tools, including random sampling and clustering, can be applied to solve coalition allocation problems without combinatorial complexity [66]. Mechanisms should be sufficiently adaptive, so that they can adjust to the evolving nature of social relations and group goals.

Some members may show opportunistic behaviours, which may endanger the functioning of a smart energy neighbourhood. In this regard, the developed mechanisms should be designed to consider and prevent such activities, for example by enforcing penalties for untruthful biddings or deceptive behaviours. This also requires transparency and accountability for decisions taken by members and the smart energy neighbourhood as a whole. Notice however that members entering a smart energy neighbourhood to pursue an opportunistic agenda, when uncovered, may be exposed to public blame through the same network of social relationships that they were trying to exploit, which may represent a significant deterrent for people living in a local community [67].

Incorporating social motivator into system design could also lead to enhanced operation and planning of local energy systems by improving how demand and generation uncertainty is handled at the local level. This is particularly important due to the weather-dependence of renewable sources and the behaviour-dependence of flexible loads, including electric vehicles and smart appliances. However, this will require the development of novel data-driven approaches to model and capture complex correlations between different sources of uncertainty, without imposing unrealistic structural assumptions [68].

Finally, the deployment of smart energy neighbourhoods requires the role of distribution system operators to be reassessed [69]. Smart energy neighbourhoods could enable different local actors to organise in a more integrated way, and may also facilitate cooperative resource investments between the distribution system operator and neighbourhood members to deploy low-carbon technologies at the local level. Regulatory barriers would need to be addressed to create an appropriate legal framework for (i) energy transactions between members, (ii) shared usage of distribution network assets, and (iii) access to the wholesale and balancing markets by distributed energy resource owners [70].

## 7. Conclusion

The concept of smart energy neighbourhoods aims to place collective human behaviours and social relationships affecting them at the centre of local energy system design. This could offer significant value, both to communities and energy systems. By leveraging the network of social relationships that exist in local areas, smart energy neighbourhoods can enable cooperation and collective actions towards shared objectives, such as supporting vulnerable people and facilitating the adoption of climate change mitigation measures, which can accelerate the transition towards the future, low-carbon energy system. Local energy system operation can also be enhanced by embedding social motivators into how energy systems are operated and planned, allowing complex human behaviours to be better captured and modelled. Finally, by developing bottom-up user-centred participation and coordination mechanisms, where local members can determine operating rules, fair allocation principles and shared objectives, smart energy neighbourhoods have the concrete potential to lead to more just energy systems, which recognise the importance of different members' preferences and needs.

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