



## Original research article

## Energy communities as demand-side innovators? Assessing the potential of European cases to reduce demand and foster flexibility

Jake Barnes<sup>a,\*</sup>, Paula Hansen<sup>a</sup>, Tanja Kamin<sup>b</sup>, Urša Golob<sup>b</sup>, Monica Musolino<sup>c,1</sup>, Agatino Nicita<sup>c</sup>

<sup>a</sup> Environmental Change Institute, University of Oxford, Oxford University Centre for the Environment, South Parks Road, Oxford OX1 3QY, United Kingdom of Great Britain and Northern Ireland

<sup>b</sup> University of Ljubljana, Faculty of Social Sciences, Kardeljeva ploščad 5, 1000 Ljubljana, Slovenia

<sup>c</sup> Istituto di Tecnologie Avanzate per l'Energia "Nicola Giordano", Consiglio Nazionale delle Ricerche, Salita Santa Lucia Sopra Contesse, 5, 98126 Messina, ME, Italy



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## ABSTRACT

Energy communities (ECs) are widely recognised for their potential to generate renewable energy. By contrast, the capacity of ECs to reduce energy demand and foster flexibility has attracted little attention to date, despite their theoretical potential to do so. To address this gap, we apply three perspectives – social representations theory, actor-network theory, and business models – to the analysis of nine case studies based in six European countries (Germany, Italy, Slovenia, Sweden, Netherlands, and United Kingdom). The core of the article comprises analysis of the nine cases from each perspective. Our results highlight the (un)intended effects of ECs on the energy representations of members; the configurational work required by focal actors to assemble new socio-technical configurations; and the value creation and capture opportunities open to ECs in the creation of novel business models; These factors in turn impact whether and how ECs achieve demand reduction and flexibility. We summarise and discuss these results in a process of meta-theoretical triangulation to produce a multifaceted and relational account of the potential of ECs to develop demand-side solutions. This leads us to conclude that ECs have a distinct capacity to develop demand-side solutions, rooted in the creation of innovative socio-technical configurations; and that this distinct capacity of ECs has the potential to complement and extend the contemporary focus on the use of market mechanisms to achieve demand reduction and increase flexibility.

## 1. Introduction

Decarbonising energy systems is a pressing societal challenge. To date scholarly and policy attention has focussed on supply-side solutions, such as the deployment of renewable generation technologies and their integration within energy markets [1,2]. Whilst important, there exists a growing consensus that decarbonising energy systems also depends on confronting two further challenges: Reducing energy demand, so that new renewable generation projects displace existing fossil assets rather than meeting rising demand, and fostering greater flexibility in energy demand, so that demand better matches supply of electricity based on variable, renewable sources [3–5]. Both challenges point towards a greater focus on demand-side solutions to complement supply-side strategies [6,7].

One actor experimenting with both supply and demand solutions are energy communities (ECs). With antecedents in community-organising

in Denmark [8], Germany [9] and the UK [10,11], ECs are taking off across Europe [12–16] facilitated by the EU's latest Energy Union strategy [17]. In theory, at least, ECs are well placed to develop demand-side solutions. Contemporary research suggests ECs are “extraordinarily multifaceted” [18], “essential cornerstones to the overall success of the Energy Transition” [17], configuring off-the-shelf technologies, with novel technical and social ideas and business models, to create new ways of collectively thinking and acting on energy [19,20]. Despite this, the capacity of ECs to reduce demand has attracted considerably less attention than their potential to generate renewable energy [7,18,21,22]. Research into the potential of ECs to foster demand-side flexibility has largely been confined to the engineering literature where it is principally treated as a technical challenge (e.g., [23]). To the best of our knowledge, no studies have yet addressed the potential of ECs to develop solutions to reduce demand and foster demand-side flexibility.

\* Corresponding author.

E-mail address: [Jacob.barnes@ouce.ox.ac.uk](mailto:Jacob.barnes@ouce.ox.ac.uk) (J. Barnes).

<sup>1</sup> Present address: University of Messina, Piazza Pugliatti 1, 98122 – Messina, Italy

This paper addresses this gap. It asks the overarching question: What is the potential of ECs to develop demand-side solutions to reduce energy demand and foster demand-side flexibility?

In this paper we define ECs following Blasch et al. [24], as “associations of actors engaged in energy system transformation for reduced environmental impact, through collective, participatory, and engaging processes and seeking collective outcomes”. Doing so we build on extensive, ongoing debates on the difference between community and commercial actors in energy systems (e.g., [25–27]) whilst recognising the diversity of actors and motivations driving contemporary activity [28,29].

To address our overarching research question, we apply meta-theoretical triangulation [30] by applying theories with different starting positions and loci of interest to nine European case studies. This allows us to expose a multifaceted, relational, and situated understanding of ECs.

- Social representations theory (SRT) focuses on the interaction between meaning and action and is mobilised to understand how normative ideas, like demand reduction, can lead to progressive actions.
- Actor network theory (ANT) conceives ECs as networks of social and technical actants and is mobilised to gather insights on how ECs create innovative socio-technical configurations
- A business model (BM) perspective emphasises how value is created, delivered, and captured by actors operating within markets and is mobilised to understand if and how reducing and flexing demand present opportunities for value creation and capture.

Each approach privileges competing ontological views: whilst SRT is centred on meanings and beliefs, a BM perspective emphasises value creation, and ANT adopts a relational view. Their analytical integration in relation to the same research question allows us to strive for deeper insights on the nature and potential of ECs to reduce energy demand and foster flexibility. Based on this analysis, we seek to determine the potential of ECs to develop demand-side solutions.

The paper proceeds as follows. Section 2 situates demand reduction and demand-side flexibility in the context of net zero energy systems and outlines means of achieving them. It then locates the potential of ECs to develop demand-side solutions. Section 3 introduces the three theoretical perspectives used. Section 4 sets out our approach to studying ECs and the ECs studied. Section 5 presents results from the application of the three perspectives. In Section 6 we summarise and discuss the results as a process of meta-theoretical triangulation. Section 7 concludes.

## 2. Energy demand, flexibility, and energy communities in net zero energy transitions

### 2.1. Realising demand reduction and flexibility

The potential to reduce global energy demand is large and widely acknowledged as essential to achieve sustained progress towards decarbonisation targets, especially in the period to 2030 [5,31,32]. The importance of demand reduction to the creation of net zero energy systems is clear. The higher demand is, the more renewable generation is required, and the slower renewable generation assets displace carbon intensive alternatives (because they must first meet growing demand).

Reducing energy demand can be achieved by avoiding completely or reducing the need for energy services, such as lighting, heating, or cooling; by shifting how energy services are delivered; and by improving the energy efficiency of devices and energy systems [6,31,32]. This tripartite framework offers a transdisciplinary approach to identifying demand-side solutions but lacks specific examples of what (i.e., strategies) can be employed by actors (in our case ECs) to promote reductions in energy demand.

From an engineering perspective, reducing demand entails improving the thermodynamic efficiency of energy conversion technologies, such as boilers, and improving the capacity of passive systems

to retain energy (e.g., increasing thermal efficiency of houses) [33]. Improvements to the efficiency of technologies (i.e., more or the same energy service for less fuel input) can be made at any point of the energy value chain [34], the sum of which traditionally accounted for overall system efficiency [35]. Under this view, energy efficiency can be achieved through the inclusion, upgrading and/or adoption of more efficient technologies and processes.

Applying this engineering perspective to services or systems is challenging. It requires specifying relevant spatial and temporal boundaries, units of measurement, as well as a reference point against which savings can be measured [33]. Calculating the energy efficiency of services and systems is subsequently hard to measure and may not lead to reductions in energy demand. Device efficiency does not guarantee reductions in overall energy demand: being efficient does not necessarily correlate with low demand, where rebound effects can negate expected savings at a household or system level [36]. Strategies to avoid energy demand subsequently require remaking socio-cultural expectations and practices, knowledge, and socio-technical infrastructures. Strategies may include rethinking building design practices, promoting tele-working, fostering active travel, or remaking energy relations [31].

How efficient energy systems are can no longer be considered as the sum of device or system efficiencies. For systems in which generation sources are renewable, effectively free but variable, it is flexibility in the timing of demand that is likely to determine how efficient systems are. Instead of minimising the (limited) resources required to deliver a given energy service, system efficiency now concerns delivering more energy services from increasingly variable resources [35]. This points to the importance of flexing remaining demand in order to meet available renewable supply (Fig. 1).

Demand-side flexibility can be fostered in multiple ways. It can result from the adoption of distributed generation where consumers are motivated to maximise self-consumption [37]. Historically, this has only occurred where generation and use are co-located. The resulting flexibility is hard to identify and value because it requires comparison to counterfactual use patterns [35]. A second strategy, actively promoted by governments and regulators, is demand response, commonly defined as changes to the timing of demand, stimulated by price signals, and delivered either individually or collectively [38]. It can be practice-led (i.e., stimulated via variable pricing structures [39] or via incentive-based schemes, such as direct payments or bill credits) or be appliance-led (i.e., stimulated via the automated control of distributed energy resources) [35]. Demand response can occur implicitly, through consumers observing prices and adjusting their demand accordingly, or explicitly, where consumers offer a flexibility service (a change in demand) to local or national markets [40,41]. Strategies to foster flexibility subsequently include deployment of distributed generation, engagement with new pricing structures, the introduction of new, smart infrastructures and products, or engagement with new markets.

In sum this means reducing energy demand (whether via avoiding energy needs, shifting how services are delivered, or improving efficiencies) and/or flexing demand is not just a technical challenge [4,33,42–44]. Moving to new energy carriers or service delivery modes will require new knowledge, competencies and skills of users and service engineers, and a broad array of technical and social innovations in consumer practices, business models, regulations, and markets [45]. Because of the interlinked and interdependent nature of these changes, approaches to reducing energy demand are rarely straightforward and may include all three approaches (avoiding, shifting and improving). Radical reductions are likely to require the creation of new systems for delivering energy services [46].

### 2.2. The potential of ECs to develop demand-side solutions, their direct and indirect influence

The potential of ECs to develop demand-side solutions is often premised on distinctive qualities of community-based action on energy.

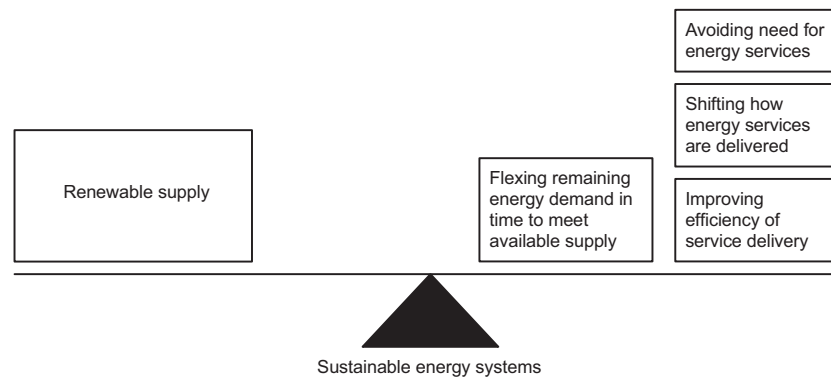


Fig. 1. Contributions of the demand side to the creation of sustainable energy systems (authors own figure).

Existing research suggests community-based activity differs from public or private-led interventions in at least four ways. First, community projects tend to be multi-faceted: they rarely address one issue in isolation but combine changes in technology with behaviour change, in ways that fit with the grain of existing community landscapes [47]. Second, by acting in groups, community action reframes the challenge of individual behaviour change, with its associated structural limitations, and fosters collective responses that challenge and remake social, economic, and technical contexts to encourage increasingly low-carbon lifestyles [48,49]. Third, through collective action, communities are thought to enable participation in energy issues [50]. Collective action is thought to help reorientate the role of members from passive consumers to active stakeholders in energy systems. This is seen as central to unlocking the potential benefits of ECs for more active demand-side management [37,40,51,52]. Fourth, existing levels of trust between members and community organisations position ECs as influential intermediary actors operating between governments, industry, and energy systems [45,53]. These qualities point towards ECs as occupying a unique position to develop demand-side solutions. It posits ECs as acting at a meso-scale, beyond the structural limitations of individualistic behaviour change programmes and technological substitution policies, but below macro approaches that target energy prices and markets at a whole system level.

Reviews of existing EC activities suggest most projects are focussed on renewable self-consumption and surplus generation trading [13,54]. Few studies have focussed explicitly on the potential of ECs to reduce demand or foster demand-side flexibility. Of these, Bauwens and Eyre [55] found a positive correlation between membership of an EC and reductions in energy demand from a survey of 3988 members of a Belgian cooperative. Work by Hoppe et al. [21] on EC members' engagement in energy-saving actions and self-reported energy demand reduction supports this. They report 38.7 % and 64.7 % of members of two ECs surveyed indicated saving energy since joining the cooperative, but only 18 % and 37 % of respondents attributed this to EC measures they were directly exposed to. Two means by which ECs influence their member's demand can subsequently be inferred: (1) via direct exposure to EC measures (e.g., an awareness raising campaign or changed socio-technical infrastructures), and (2) through the indirect influence of community membership on practices and behaviour (e.g., changed expectations about appropriate behaviour). Finally, work by Roth et al. [56] suggests members of collective self-consumption ECs are more open to providing flexibility where there is a choice between consuming or selling their production.

These insights - on the distinctive qualities of community action and on the potential of ECs to reduce demand and foster flexibility - provide the foundation on which nine European case studies are analysed from three different perspectives. In the next section we introduce these perspectives and their loci of interest.

### 3. Theory: three perspectives on ECs' potential

#### 3.1. Social representations theory: from social acceptance to action

SRT is a theory of social knowledge that examines how the formation of representations of a given issue (e.g., energy) shape the behaviours of individuals and of communities to which they belong [57–59]. Considering that beliefs, practices, and behavioural outcomes are affected by shared meanings of people involved in ECs, SRT is useful to study the success of ECs in delivering demand-side solutions.

SRT, a socio-cognitive approach, aims to determine the relation between human psychology and new social and cultural trends, such as sustainability and renewable energy, “by focusing on everyday communication and thinking” [58]. It emphasises that there can be no sense-making or change “outside a specific interactional context” [60]. SRT has been used to understand public responses to, and social acceptance of, renewable energy technologies and energy storage [61,62].

The focal concept is that of social representations (SRs): “structures that comprise simultaneously and inextricably, cognition, affection and action” [63]. The cognition, affects, and practices are combined as ‘patterns’ to describe ideas about objects and concepts. SRs are “produced by members of a group through social practices and during formal and informal communication processes” [64]. In relation to clean energy and ECs, they reflect models of understanding about energy behaviour that occurs through social networks or communities [65].

SRT assumes that individual beliefs and knowledge about energy-related behaviour have social origins; they are acquired and shared by individuals, in collectives, with similar views and experiences [66]. Moreover, SRs are normally shaped by motivations a particular group of individuals shares [58], legitimising the group's knowledge system that also influences interests and builds group identity [66]. Nevertheless, SRT also tells us that individuals (or groups) can simultaneously have multiple, and sometimes polarised, views (representations) about a certain idea [67]. Therefore, social interaction and discourse are integral in shaping SRs that are constantly being re-negotiated within the group or beyond [66].

By emphasising social change and the interplay between beliefs, norms, and practices [67], SRT also helps explain to what extent the ideas of renewable energy and ECs (with encoded assumptions about changes in energy consumption behaviours) can receive wide societal support and progressively lead to certain actions, such as energy demand reduction. However, both clean energy and reducing energy demand seem highly susceptible to contextual influence, which is, in our case, also embodied in the current understanding of consumption and consumer culture. Thus, to foster more ‘appropriate’ consumption practices it is first necessary to understand existing energy consumption beliefs and practices within ECs. These may be far removed from ideas of energy demand reduction yet still significant and meaningful for consumers themselves [68].

In mobilising SRT we ask: how does involvement in ECs affect representations of energy use? To what extent do these representations

include energy demand reduction and increased flexibility in demand (both in terms of beliefs and practices)?

### 3.2. Actor network theory: ECs as assemblages

ANT builds on a flat and relationist ontology [69,70] that defies conventional boundaries between the social and the material. It considers human and non-human entities as equal actants in the world who only acquire meaning and purpose through relations with others in networks. Given this ontology, ANT is applied at a micro level, where networks of actants and their relations can be traced [71]. Unlike other sociological approaches (e.g., SRT), which privilege social over material contexts, ANT asks agnostic questions of what entities constitute research problems (i.e., ECs), how they are associated, and how new actions and outcomes, such as demand reduction, are mobilised as a consequence of networks [72]. In relation to our overarching research question, ANT provides a means to understand the ‘configurational’ work [19] performed in ECs to create innovative socio-technical configurations: new alliances of actors and technologies, in specific socio-economic, spatial, and institutional circumstances. Given the socio-technical nature of ECs, and the interlinkages and interdependence of social and technical changes required to reduce demand and foster flexibility, ANT facilitates understanding of how ECs combine actants into networks to realise innovative socio-technical configurations.

In the following, we mobilise Callon’s sociology of translation [73] as a framework to understand how ECs and the actors within them assemble networks: the process through which social actors define and attribute roles to others, make connections and build networks. The translation process involves several steps. First, an EC needs to problematise a situation, by articulating an urgent and unifying problem. It must also make itself indispensable to others in the presentation of a solution. Initial network builders might comprise central EC practitioners, managers, or focal members [71], who detail an issue and position the EC as the means for its reconciliation. Crafting solutions and assembling networks subsequently involves positioning new actants (often new technologies) between existing entities to create new connections and enrolling all into new networks by interconnecting the various roles of actants. Tracing what entities are enrolled and how, whether they are intentionally engaged, and the extent to which they play (un-)desired roles, all contribute to explaining the success or failure of assembled networks.

ANT thus provides a useful perspective to understand the challenges involved in realising innovative actor networks [71] and is valuable here in explaining the capacity of ECs to deliver demand reduction or flexibility through network formation processes. ANT raises two central questions for this paper: Are demand reduction and demand-side flexibility problematised by actors involved in setting up ECs? And what does the process of translating ideas into functioning actor networks reveal about the capability of ECs to deliver on either challenge?

### 3.3. Business models: ECs as value creators

A BM is a description of how an organisation creates and captures value. Despite frequent usage, there is no widely accepted and shared understanding of what comprises a BM [74]. Scholars have variously highlighted the activities involved in delivering a firm’s strategy [75], the logics behind activities [76], and the essential elements of any business (e.g., BM canvas) [77]. Analyses of BMs within energy system transformations stress the need to analyse how value creation and capture is influenced by and dependent on the alignment of other system elements, including market rules, policies, regulations as well as user practices [78–80]. Whilst BM research has traditionally focused on commercial firms operating within competitive markets, growing awareness of the ecological crisis has spurred interest in alternative, non-commercial value logics [81], such as the pursuit of social or environmental value. Commercial, municipal, and community value



Fig. 2. Conceptual business model framework, adapted from [86].

logics have been shown to influence BMs in energy systems, producing divergent material outcomes [82]. At the same time, community activity on energy has been progressively shaped by government policy, forced to operate as commercial actors within emerging decentralised energy marketplaces [11]. This trend is continued and extended through the recognition of ECs by the EU as legal actors within energy markets. The analysis of EC activities through BM approaches is subsequently becoming increasingly popular as a means to differentiate activities undertaken, and the potential of ECs for system decarbonisation.

Here, we limit our analysis to the three most widely discussed elements of BMs – value proposition, value creation and delivery, and value capture (Fig. 2) – whilst recognising that creating and delivering value requires the alignment of multiple actors and activities in wider, evolving energy markets [11,83,84]. The value proposition refers to the value or utility derived from the goods or services the EC provides to its members or customers [85]. How ECs create and deliver value sits at the heart of business models and includes the key activities, resources, and partners required to deliver a product or service [84]. Value capture encompasses the balance of costs and payments, their reconciliation, and/or generation of profits [86,87].

Taking forward this understanding of ECs as organisations operating BMs we ask: how are demand reduction and demand-side flexibility mobilised within value propositions, and what opportunities do they present for value creation and capture?

## 4. Research approach and methodology

### 4.1. Analytical framework

We are interested in how ECs influence the energy consuming behaviour and practices of members, either directly through specific strategies or indirectly through changed social and material contexts of action. Each perspective described in Section 3 has a different empirical emphasis and central concepts which impact how each interprets our primary research question. The main features of each perspective and the data sources used for analysis are presented in Table 1.

### 4.2. Data collection methods

Given our research problem and analytical approach, contemporary EC initiatives comprise the unit of analysis. To answer our overarching research questions, we draw on nine case studies of ECs across Europe, compiled using mixed methods. Cases (detailed in Table 2) were sampled for diversity of activity (encompassing generation, efficiency, storage, and trading of electricity), range of actors involved, and use of innovative technologies. Our mixed methods design included:

- Workshops: Nine online workshops were undertaken between March and May 2020. Each followed a standard format involving between 2 and 9 participants (mean = 5) and covered the same topic areas (introduction to the ECs, novelty, actors involved, contextual barriers and enablers of progress).
- Interviews with central practitioners and partners: 35 semi-structured interviews were conducted online between May and June 2020, with people centrally involved in the creation of ECs.



**Table 1**

Three perspectives mobilised to study demand-side solutions of ECs.

	Social representation theory	Actor network theory	Business model perspective
Empirical emphasis	Meanings	Relations, agency	Value
Key concepts	Social change; Enacting and resisting social change; Correspondence between action and agreement	Networks; Translation process; Problematization; Cooperation between actants; spokesperson	Value proposition; Value creation and delivery; Value capture
Interpretation of primary research question	How does involvement in ECs affect representations of energy use and to what extent do these representations include demand reduction and demand-side flexibility (both in terms of beliefs and practices)?	Are demand reduction and demand-side flexibility problematised by actors involved in setting up ECs? What does the process of translating ideas into functioning actor networks reveal about the capability of ECs to deliver on either challenge?	How are demand reduction and demand-side flexibility mobilised within value propositions and what opportunities do they present for value creation and capture?
Data sources employed for analysis	Interviews with EC members	Workshops with central actors; Interviews with EC members; Interviews with EC practitioners and partners	Workshops with central actors; interviews with EC practitioners and partners; document analysis

**Table 2**

Energy community case studies.

Name	Description	Country, setting	Started	Status	Interviewees
Buurtmolen Herbaijum	A renewable energy cooperative that facilitates member consumption of electricity from a local collectively owned wind turbine	The Netherlands, rural	2017	Operational	4 members, 3 founders
Dalby Solby	A housing cooperative that aims to promote sustainable living and has implemented electricity generation and energy saving measures on communal buildings, led by a working group	Sweden, sub-urban neighbourhood	1978	Operational	5 resident members, 7 working group members
Energy Local	A new approach linking local renewable generators with local consumers to reduce costs and increase local consumption of renewable energy through the creation of 'Energy Local clubs', using smart devices with communication and data transfer technologies.	United Kingdom, rural	2016	Expanding	7 members, 2 founders, 4 club advisors, 3 local club representatives
Economia Rinnovabile e Circolare (ERiC)	A non-profit organisation promoting a sustainable circular economy by facilitating household purchase groups for solar PV.	Italy, regional (Sicily)	2018	Operational	3 members, 1 manager, 1 employee
GEN-I Jesenice	Apartment owners working in cooperation with a national utility to lower bills and reduce carbon emissions through implementation of onsite measures including solar PV and heat pumps	Slovenia, apartment block	2019	Operational	4 residents, 1 lead resident, 2 utility project managers
Project Z <sup>a</sup>	Households trading surplus PV generation via a utility designed platform, to maximise local consumption and reduce reliance upon the grid.	Germany, neighbourhood	2019	Pilot (30 households)	1 senior innovation manager
Solidarity & Energy Social Housing (SO_EN)	A community-orientated energy service company premised on fostering energy equity and reducing social inequality through the provision of generation and storage assets and a 'social algorithm' to distribute payments between residents.	Italy, apartment block	2019	Under development	5 prospective members, 2 engineers, 1 ESCO manager, 2 architects, 3 social workers, 1 technology provider, 2 researchers
sonnenCommunity	A top-down 'virtual community' of prosumers sharing energy between members through cloud-based software.	Germany, national	2016	Expanding	5 members, 1 Vice president business innovation
Zuiderlicht	A cooperative of approximately 900 members, who collectively own and manage 18 roof-mounted PV installations.	The Netherlands, city	2013	Expanding	6 members, 2 founders

<sup>a</sup> Due to commercial sensitivity, project identifiers, such as project name and the name of principal actors, have been removed. The case will be referred to as Project Z.

Each was conducted in native language and followed an interview guide covering emergence of the ECs, actors involved, business activities, value creation, knowledge and skills involved, and problems encountered. Interviewees were selected using a snow-ball sampling technique [88], ending when all central actors involved in ECs were interviewed.

- Interviews with EC members: 39 semi-structured interviews with EC members were carried out between September and October 2020. Each was conducted in native language and followed an interview guide, covering the following topics: (1) EC members' background and involvement with the EC; (2) knowledge and skills perceived as necessary for joining the EC and the process of learning EC-related knowledge and skills; (3) barriers and incentives related to EC membership; and (4) everyday life and (social) practices in the EC.
- Collection of publicly available documents, such as EC websites, EC project reports, and news articles about ECs.

#### 4.3. Analysis

##### 4.3.1. Social representations theory

The qualitative analysis of the interview data was done with MaxQDA2020 software (VERBI Software, 2019), and manually, utilising the translated transcripts and the reports completed by national research teams. Within the collected data we aimed to identify themes and patterns to construct a more general set of assumptions and propositions about the EC phenomena. Led by the guidelines established by Braun and Clarke [89], we identified and described core themes related to the meanings of energy and practices related to energy use among research participants. We assigned codes for each core theme of the identified representations (in-vivo coding) and created a central 'codebook' to collect insights from EC members. At the beginning of the open-coding, iterative procedure, codes were attributed to smaller meaning units (statements that had some common meaning). During this process, the coding scheme was constantly upgraded. In the later phase, we clustered

codes with commonalities into the thematic categories, exploring coherent configurations, and continuing with the process identifying higher-level thematic categories [90]. In this paper, we present the findings concordant with the SRT approach, which focused on the meaning people attribute to their behaviours and practices related to energy production and consumption as well as the motives behind them.

#### 4.3.2. Actor network theory

Application of ANT followed three steps. First, we analysed interview and workshop materials to identify focal actors involved in defining the issue(s) and proposed solutions of ECs. In practice, this involved identifying initial network builders and articulating how each EC was problematised. Once complete, all nine EC problematisations were reviewed to assess if and how they featured demand reduction or demand-side flexibility. Second, we inductively identified entities involved in each case study, both social and material actants, and their connections. This resulted in a set of actor-technology maps, detailing the primary actants involved and their connections, which were reviewed by central practitioners and subsequently refined. Third, in the subset of cases where demand reduction and demand-side flexibility featured within the problematisation of ECs, we analysed network formation processes to understand the capacity of ECs to deliver demand reduction or demand-side flexibility. This involved examining which new actants were introduced by focal network builders, asking of their intended and unintended connections and implications, and reviewing how actants responded to being enrolled in networks.

#### 4.3.3. Business models

Identification and analysis of the BMs developed by ECs followed an iterative process with three streams of analysis being of relevance: (1) thematic analysis of contextual elements enabling and hindering the emergence and operation of cases, (2) inductive tracing of financial and electrical resource flows building on prior actor-technology mapping, and (3) abductive application of the BM canvas [91]. Workshops with core practitioners and partners were used to gather an initial understanding, interviews with practitioners and partners provided further detail. Draft case study reports, covering actors and technologies involved and central BM elements were reviewed by practitioners, their corrections included before being published online [100–108]. Ongoing dialogue with practitioners allowed for refining understanding of each case on an ongoing basis. In Section 5.3, we summarise our findings on the content of each BM before discussing where and how demand reduction or demand-side flexibility were mobilised to create, deliver, and capture value and under what context conditions.

### 5. Results: navigating the potential of ECs

In this section we present the results of assessing the case studies through three analytical perspectives.

#### 5.1. Dominant representations of energy and their impact on the level and timing of demand

Across all interviews with EC members, we identify three dominant representations of energy use. We introduce each below, thereby addressing the first part of our SRT sub-question (see also Annex 1 for a summary of these representations with indicative quotes). We then turn to address the second part: to what extent these representations include demand reduction and demand-side flexibility (in terms of beliefs and practices).

First, when EC members discussed energy and their involvement in their ECs, many went into detail about **energy costs** and the financial benefits of their EC membership. For almost all respondents, reducing household energy bills was an important outcome of participation. Some participants explicitly linked improved energy affordability to EC membership. EC members saw various ways in which their energy-

related costs were reduced after joining an EC. Adopting efficient technologies, such as installing a heat pump (GEN-I Jesenice), using energy-saving light bulbs (Dalby Solby), and installing motion sensors to turn lights on and off in common areas of a community building (GEN-I Jesenice), were measures associated with lower energy costs and increased affordability. Other participants highlighted that after joining an EC they adopted more efficient energy appliances and technologies, such as installing triple glazing and LED lighting, which reduced energy costs and enhanced affordability. For others, affordability was linked to maintaining and, in some instances, increasing energy demand whilst keeping costs at a similar level.

Second, EC members addressed energy issues in terms of **energy independence**, particularly from energy suppliers and traditional energy systems. The use of EC-owned technology for energy production, such as in Buurtmolen Herbaaijum or Dalby Solby, was perceived by many as a source of freedom or 'independence from bigger energy suppliers' and their pricing policies. Access to power generated by local renewable installations (as in Energy Local), and in some cases storage equipment (e.g., sonnenCommunity), was also perceived as improving energy independence, as was the freedom to use electrical appliances (e.g., washing machines or water heaters) when convenient rather than being limited by time-of-use tariffs (for access to more affordable energy).

Third, although EC members were aware of the **environmental footprint of energy use** before joining their EC, reducing this footprint was a popular motive for joining. The question of where the energy they use comes from was important to all participants. In reducing the environmental footprint of their energy use, most EC members considered the means of energy production to be more important than levels of consumption. In practice, we understand this to mean EC members strive to maintain their standard of living whilst reducing their environmental footprint as far as possible.

We find that the relationship between these representations and demand reduction and flexibility is complicated. Whilst there is an intuitive relationship between consumers reducing energy costs and demand, energy costs were also important in determining how much energy members consumed, whether this was more or less than before. This highlights a demand reduction issue that is well-documented in economic discussions (see for instance [33]): the price of energy (and its overall affordability) does not correlate with demand. Reduced energy costs do not necessarily result in increased energy demand (nor do increased energy costs always reduce energy demand). In the case study energy representations, affordability, when combined with independence and the environmental footprint of energy, resulted in both reductions and increases in energy demand. Overall, the interaction between these representations were observed as legitimising increased energy consumption because energy supplied via ECs was perceived as being cleaner, cheaper, and more guilt-free than in traditional energy systems. At the same time, there appears to be minimal evidence to suggest these representations encouraged demand-side flexibility. On the contrary, comments relating to independence from time-of-use tariffs suggest that demand-side flexibility may even have been reduced (by using energy at times less favourable to the grid).

This analysis illustrates that participation in ECs affects beliefs about energy, and the meanings individuals attribute to their energy related practices. From the SRT lens, studied ECs did not directly encourage intentions associated with reducing or shifting the timing of energy demand to better match available generation. Yet, there is evidence to suggest participation in ECs indirectly influenced practices beyond those of primary interest. We attribute this indirect impact of ECs to heightened awareness of the environmental footprint of energy and label this result a spill-over effect, following Poortinga et al., [92]. For instance, some participants described practices that included reductions in resource use and transport. In essence, it can be concluded that involvement in ECs encouraged members to change their energy perceptions and develop new practices in their daily lives. Taken together,

however, these changed representations had varied outcomes, reducing demand in some instances, and legitimising increased demand in others. Meanwhile, there was little (and sometimes counterproductive) impact on flexibility.

## 5.2. Creating actor networks to reduce and flex demand

Applying ANT to our case studies, we ask if and how reducing or flexing demand was problematised by our cases, and subsequently, what the process of translating ideas into functioning actor networks reveals about the capability of ECs to deliver on either challenge.

### 5.2.1. Problematising demand

Demand was problematised by focal actors in four of the cases studied. For the founding activists of Dalby Solby, reducing demand was part of the initial problematisation which saw the creation of a new 'solar village' as a (resource-efficient) means for eco-conscious living. For the engineers, architects, and technology providers involved in the creation of SO\_EN, reducing and flexing the timing of demand was viewed as essential to maximising community self-sufficiency from onsite renewable generation and storage technologies. Flexing demand via batteries to make better use of onsite generation, whilst providing a range of ancillary services to local electricity markets, was central to the premise of the sonnenCommunity as set out by sonnen managers. Finally, shifting the timing of member demand to make better use of local generation was central to the logic of developing Energy Local as set out by its founding directors (for further details of how each case problematised these issues see [Annex 2](#)).

Given that no other cases problematised demand, the answer to the first part of our ANT sub-question is that reducing or flexing demand was rarely problematised in the cases studied. In ANT terms, this limited problematisation by focal actors resulted in failure to deliver changes in demand in most cases. Moreover, in only two of the cases were reducing or flexing demand sought as a desired outcome in and of itself (Dalby Solby and Energy Local). For the remaining two cases reducing and flexing demand was viewed as a means to achieve something else (interdependence for the sonnenCommunity and maximising self-sufficiency for SO-EN).

### 5.2.2. Assembling actor networks

The cases provide a variety of insights regarding the second part of our ANT sub-question: what the creation of functioning actor networks and translation processes can teach us about reducing and flexing demand.

First, the case studies suggest that the earlier in the network formation process the issue is problematised, the larger the opportunities for reducing demand. In Dalby Solby, for instance, focal actors were able to pursue strategies that avoided the need for energy services because demand reduction was problematised before the eco-village was built. Early problematisation also facilitated enrolment of efficient technologies. Conversely, the cases suggest the more established networks are, the harder it is for focal actors to enrol new actants and re-assemble networks to avoid the need for energy services. In these instances, focal actors relied on strategies which shifted how services were delivered or improved device efficiency. A clear example of this concerns recent efforts of the energy group at Dalby Solby to replace lighting with more efficient equivalents.

Second, demand reduction was largely achieved through minor modifications of existing networks. These modifications principally involved the substitution of one actant for another, with limited impact on network relations. LED light bulbs, for instance, behave in the same way as their higher energy consuming predecessors. The prevalence of actant substitution strategies to achieve demand reduction can also be seen in GEN-I Jesenice, where, although not problematised as concerning demand reduction per se, replacing a boiler for a heat pump (thereby shifting how energy services were delivered) resulted in reduced demand. Taken together, this suggests non-human actants (mainly energy-efficient technologies) played a crucial role in assembled

networks to achieve demand reduction. Human actants maintained largely passive roles. Moreover, the success of assembled networks can perhaps be attributed to the limited number of new connections required. These new connections were principally concerned with tech-to-tech relations, with limited alterations to the relations between technology and human actants.

Third, focal actor efforts to translate increased demand-side flexibility into functioning actor networks converged in several respects. Networks assembled by Energy Local, SO\_EN, and the sonnenCommunity all showed reliance on and inclusion of a range of information and communication (ICT) technologies, featuring smart meters, algorithms, consumer access devices, and other smart devices. Each EC experiencing similar issues to each other. For instance, the inclusion and use of smart meters was problematic for Energy Local and the sonnenCommunity as well as Project Z. In the creation of its first club during 2017 Energy Local resorted to using smart meters designed for industry because domestic smart meters being deployed at the time under a national rollout programme, did not provide the necessary functionality. In Germany, a slow national rollout of smart meters led sonnen to collect domestic generation and consumption data via ICTs integrated into their own smart home battery systems. Issues also arose around effective communication between technologies.

Fourth, these translation processes diverged in key respects. Energy Local enrolled smart metering, ICTs and algorithms in new networks to incentivise practice-led changes in demand. In this case, EC members were given agency and played an essential role, alongside all other actants, in delivering increased demand-side flexibility. Through the provision of information alongside time-of-use tariffs, focal actors sought to incentivise flexing of demand. Conversely, the sonnenCommunity assembled actor networks that are largely separate from and neatly packaged for members, to deliver demand-side flexibility. Member interaction with critical flexibility infrastructures is limited. In this sense, the actor networks assembled by sonnen are black-boxed to both members and researchers. SO\_EN also seeks to foster appliance-led demand response, with generation connected to batteries and smart appliances controlled centrally for resident members. Like the sonnenCommunity, interactions between technical actants are complex, reliant upon effective communication channels and controlled by algorithms, which remain largely black-boxed.

These latter two points suggest that considerably more configurational work is required to assemble networks capable of fostering flexibility than reducing demand via ECs. These networks require a range of smarter, ICTs to link demand to generation in new, previously unconnected ways. This reliance on ICTs is evident in both practice- and appliance-led approaches. Black-boxing new technologies and their roles from members does not mitigate against communication issues arising between technologies. Meanwhile, the increased number of actants and active relations (e.g., between smart meters, batteries, algorithms, smart devices, and members) as compared to actants and relationships in assembled networks for demand reduction, appear to create more potential for issues to arise.

## 5.3. Reducing and flexing demand through innovative business models

In this final section we present the results of the BM analysis, asking how demand reduction and demand-side flexibility are mobilised within value propositions (if at all) and what opportunities they present for value creation and capture.

The nine case studies included a variety of functional and normative offers in their value propositions, with emphasis often placed on the latter (see [Annex 3](#) for a summary of BM elements of each case study). Normative attributes of these propositions emphasised sustainability, independence, fairness, and equity through participation in the EC. Functional attributes included reduced environmental impact, access to generation, reliability, and reduced costs, but not reduced demand nor the capacity to shift the timing of demand. This answers the first part of

our BM sub-question: neither demand reduction nor flexibility play a part in the value propositions of the nine case studies. This suggests neither is sufficiently valuable, from a member perspective, to be foregrounded in the service offerings provided by ECs.

In three cases (Dalby Solby, GEN-I Jesenice and SO-EN) reducing demand was important to how they create and deliver value. What differentiates these cases from all others is their provision of energy services, such as heat and light, to their communities. In contrast, all other cases delivered electricity measured in kWh, rather than the final service it provides. This suggests that delivering services is important in understanding how these cases create and deliver value from reducing demand. By focussing on the delivery of services, the boundary of each EC's BM included the technologies and infrastructures of service delivery. Each case had direct influence and control of technologies and infrastructures within their communities. This created space in which efficient devices, services, and systems could be employed to reduce costs and increase value creation and capture in their BMs. In effect, this created space in which demand for energy services could be avoided or reduced via better design, shifted to new energy carriers, and improved through more efficient devices. To deliver energy services, each case operated behind a single meter point. This suggests electricity market rules throughout the countries studied currently do not allow for the creation of energy service BMs linking generation and demand across households.

Two cases used demand response strategies to create, deliver and capture value within their business activities. Energy Local used an implicit demand response strategy in which customer access devices were used to indicate times of local generation whilst static time-of-use pricing was used for all power requirements not met by local supply. These two forms of information provision served to encourage members to adjust their demand in order to maximise consumption of local generation and reduce bills. In contrast, the sonnenCommunity used an explicit demand response strategy: member assets were externally controlled to increase community self-sufficiency and offer demand-side flexibility as a service to local and national markets. In both cases, flexing demand, whether practice- or appliance-led, created value for the EC as a business and for its members. Increased demand-side flexibility was also observed in two further cases (Dalby Solby and SO-EN) facilitated by new relationships between technologies, infrastructures, and members, located behind single meter points. As a result, changes to the timing of demand (e.g., putting the washing on in the middle of the day) led to higher value capture opportunities (the difference between exporting surplus generation and buying from the grid). Thus, demand-side flexibility in these cases resulted from EC members being motivated to maximise self-consumption from onsite generation.

In summary, application of a BM logic to the case studies suggests reducing demand presents an opportunity for value creation and capture only where energy services are delivered. Our analysis suggests this is

currently only possible where EC BMs operate behind a single meter point. By contrast, there are two primary opportunities to create and capture value through fostering demand-side flexibility. This includes shifting the timing of demand to make business activities more profitable, or offering flexibility as a service to local and/or national energy markets and distribution network operators. The former typically involves the co-location of generation and demand within new socio-technical configurations. The latter is a form of explicit demand response, which directs attention to the importance of external market conditions as shaping what business activities are possible at any given time.

## 6. Summary and discussion

In the following we discuss the potential of ECs to develop demand-side solutions to reduce demand and foster flexibility by summarising and triangulating the central insights emerging from each analysis (Table 3). In doing so, we focus on areas of convergence and divergence between perspectives and on the implications of our analysis for research, policy, and practice.

First, the analysis shows that realising demand reduction via ECs is challenging but possible. Whilst all three perspectives point to this conclusion, their different starting positions and loci of interest indicate different explanations (Table 3). Application of ANT revealed that in most cases demand reduction was not problematised by focal actors, providing a central explanation for why it was not realised. Accordingly, ANT suggests the issue needs to be vocalised before it can be translated into practice. It also underlines the configurational effort needed to assemble new networks and relations between actants to deliver desired results. Analysis of the cases through a BM perspective led us to conclude there are few opportunities to create and capture value whilst pursuing demand reduction. Application of SRT taught us that participation in ECs affects member representations of energy in potentially unforeseen and undesirable ways (e.g., resulting in increased demand).

Each perspective also holds insights on the means through which demand might be reduced. Despite our tripartite framework (Section 2) indicating multiple ways to theoretically reduce demand, the avenues open to ECs appear more constrained in practice. ANT suggests larger opportunities to reduce demand exist the earlier in a network formation process the issue is problematised. Our BM analysis suggests reducing demand can only be achieved through the creation of energy service BMs: a particular BM currently only attainable by operating behind a single meter point as energy market rules and regulations prohibit their reach across multiple meter points. Furthermore, our ANT analysis suggests EC practitioners seeking to enrol new technologies into existing networks are limited to technological substitution: enrolling technologies into networks whilst attempting to limit engagement with, or new relationships between, members as users. The application of SRT

**Table 3**

Central insights on reducing demand and fostering flexibility derived from application of SRT, ANT and BMs perspectives to nine European case studies.

Social Representations Theory (SRT)	<ul style="list-style-type: none"> <li>• ECs affect representations of energy use in multiple, sometimes unforeseen ways.</li> <li>• Combined changes in representations can have mixed results, reducing and increasing demand in equal measure, whilst marginally supporting demand-side flexibility at best, or actively undermining it at worst.</li> <li>• Altered representations can indirectly affect practices beyond those of primary focus to ECs: changed representations can spill over into other areas of members' lives.</li> </ul>
Actor Network Theory (ANT)	<ul style="list-style-type: none"> <li>• Demand reduction and demand-side flexibility are as likely to be problematised in the pursuit of other objectives (e.g., maximising self-sufficiency) as they are on their own.</li> <li>• The earlier in a network formation process an issue is problematised, the larger the opportunities to reduce demand (e.g., through avoiding the need for energy services).</li> <li>• Demand reduction is mainly achieved through a technological substitution strategy; deploying energy efficient technology whilst limiting the engagement and interactions between new technologies and members.</li> <li>• Increasing demand-side flexibility requires considerably more configurational effort than demand reduction because networks capable of shifting the timing of demand require enrolling multiple ICTs and the creation of new relations between generation and demand. The concomitant increase in actants and connections increases the potential for issues to arise.</li> </ul>
Business model (BM) analysis	<ul style="list-style-type: none"> <li>• ECs do not foreground opportunities to reduce or flex demand in their value propositions to members.</li> <li>• Opportunities to create and capture value from demand reduction appear limited to the delivery of energy services behind single meter points.</li> <li>• A variety of opportunities to create and capture value from demand-side flexibility appear open to ECs, including via co-locating generation and consumption, introducing time of use pricing, and via direct control of load.</li> </ul>



reminds us that even in cases that seek to black-box and neatly package new relationships between predominantly technical actants, ECs may still alter representations of energy with adverse consequences. Collectively, this demonstrates the inextricably socio-technical nature of changes required to achieve demand reduction. This includes *inter alia* altering practices and the creation of new business models. It also underlines the distinctive value of ECs in reducing demand, their capacity to reconfigure collective socio-technical contexts of action.

Second, ECs can have an indirect impact on member energy demand. Application of SRT teaches us that changes in understanding and beliefs brought about by participation in ECs can lead to outcomes beyond ECs' primary goals. Any attempts at quantifying this indirect impact will be challenging, not least because of the need to isolate the influence of ECs from other factors. The existence of indirect impacts, as reported by EC members, also makes the total contribution of ECs to reducing demand hard to pinpoint and validate. Despite this, the indirect impacts of ECs should not, in our view, be ignored or side-lined. They should be considered and valued by policymakers and practitioners. For instance, joining an EC has the potential to strengthen an individual's environmental identity, which, in the long run, can spill over to other practices and outcomes, like demand reduction [93]. However, caution is also warranted. Just as altered representations can result in increases in demand, the indirect effects of representations may also be negative. Future research should thus seek to identify the prospects for positive spill-overs or negative rebound effects from ECs. Types of knowledge and skills acquired through participation in an EC are likely to determine social representations of energy by members and in turn their spill-over actions (e.g., [94]).

Third, regarding demand-side flexibility, our analysis suggests that whilst there are opportunities to create and capture value from fostering flexibility in the BMs adopted by ECs, assembling networks capable of delivering flexibility involves considerable configurational work by EC practitioners and partners (Table 3). A range of new, often smart, ICTs such as smart meters and algorithms are required. New links between generation and demand must also be created. The number of actants enrolled in assembled networks increases the potential for issues to arise. Meanwhile, our application of a BM perspective suggests two principle opportunities for ECs to create and capture value through fostering demand-side flexibility. This includes shifting the timing of demand to make business activities more profitable and developing flexibility as a service to other system actors or markets. The latter is a form of explicit demand response, which is being actively encouraged by policy and market design. The former incentivises changes in demand via the creation of new actor networks linking supply and demand in new ways, often co-located at a single network connection. We label this approach *flexibility by design* and contrast it with flexibility by contract, encouraged through explicit demand response. ECs' distinctive capacity to foster flexibility by design – by reconfiguring collective socio-material contexts of action – is currently less recognised by policymakers and markets, although it is beginning to receive some attention as a system benefit of individual self-consumption [95]. Our analysis supports the idea of ECs operating at a meso-scale and of ECs as being commonly motivated by ideas of independence and increased self-sufficiency [96]. This combination, we suggest, presents an untapped potential to foster demand-side flexibility. Analysis of current and future policy mechanisms through which ECs might deliver flexibility by design presents a potentially fruitful line of future inquiry.

Fourth, application of SRT teaches us that representations of energy use are important and cannot be ignored in the development of ECs. Our findings suggest all ECs affect representations of energy use, which can result in varied, unforeseen outcomes. Our analysis stresses both desired and undesired outcomes. Arguably, this insight is particularly pertinent given the prevalence of ECs relying on technology-focused, often black-boxed demand-side solutions. These remain risky, although potentially attractive given the reduced need for members to understand new technologies and develop new routines and practices around them. Reduced energy use achieved through technological substitution may be

undermined or even reversed by changed representations of use. Rather than presenting shortcuts, technology-based solutions may in fact present dead ends. This underlines the importance of developing holistic demand-side solutions that equally engage social and technical elements of socio-technical configurations. We suggest further research is required into the effect ECs have on representations of energy use, in particular if and how some (combinations of) representations may be more useful than others in the creation of net zero energy systems.

Finally, we argue the three perspectives we mobilised all direct attention to a single unifying insight, namely: the motivations of people to join ECs, particularly independence and increased self-sufficiency, are critical to realising demand-side solutions via ECs. On the one hand, striving for independence and associated ideas of self-sufficiency translated into EC strategies to reduce and flex demand where they did not previously exist. Efforts to reduce demand enabled renewable generation to replace existing fossil-fuelled or non-community supply, whilst shifting the timing of demand was viewed as crucial to making better use of available community generation (rather than exporting to the grid). Independence was also identified as one of three dominant representations of energy across all cases, whilst the value propositions of ECs emphasised normative over functional elements like demand reduction. Given the expected marginal returns to consumers from delivering flexibility as a service and the infancy of local flexibility markets across the EU [97], finding alternative motives to reduce demand and foster flexibility appears crucial to developing demand-side solutions. Our work is thus a counterpoint to existing concerns over the potential for grid defection by prosumers and communities (often reduced to a motivation for independence), which can result in system management issues whilst undermining traditional utility business models [98,99]. More research is required to investigate how these motivations might be harnessed to achieve change whilst minimising associated undesirable impacts.

## 7. Conclusions

This paper inquired into the potential of ECs to develop demand-side solutions to reduce energy demand and foster demand-side flexibility. Using an approach based on meta-theoretical triangulation, we applied three different perspectives – each with different starting positions and loci of interest – to nine case studies of ECs to produce insights on the potential of ECs to reduce demand and foster demand-side flexibility. To this end, meta-theoretical analysis provided a rich, multifaceted, and relational account.

In summary, we find ECs have a capacity to develop demand-side solutions that is distinctive from government- and business-led approaches. Our analysis suggests reducing demand via ECs is challenging but possible. First, contemporary ECs rarely prioritise demand reduction itself but may address it in the pursuit of other objectives, notably increased independence, and self-sufficiency. Second, there are few opportunities to create and capture value from demand reduction. Third, creating innovative social configurations through network formation processes is challenging despite multiple theoretical options to avoid the need for energy, shift how energy services are delivered, or improve energy efficiency. In practice, our analysis suggests it requires dedicated work to identify and exploit a limited range of possibilities.

With regards to demand-side flexibility, our analysis suggests assembling innovative socio-technical configurations capable of flexing demand requires considerably more configurational work than that required to reduce demand. The range of new technologies involved provides one explanation for this. The need to link supply and demand, in many instances for the first time, provides a second explanation. Like demand reduction, our analysis suggests flexibility need not be a primary motivation for focal actors. It can arise where focal actors are motivated to achieve increased independence and self-sufficiency, its realisation supported by two value capture opportunities: shifting the timing of demand to make business activities more profitable or offering flexibility as a service. The former is typically incentivised through the creation of new actor networks linking supply and demand in new ways,

often co-located. The latter relies on local or national flexibility markets.

Taken together, this work points to ECs as holding a distinctive capacity to develop demand-side solutions. This capacity, we argue, involves operating at a meso-scale to assemble innovative socio-technical configurations capable of fostering demand reduction and increased demand-side flexibility by design. This capacity complements and extends the contemporary focus of policy-makers and market architects on delivering demand-side solutions through market mechanisms, such as demand response and the creation of local energy markets. Such markets are being developed and tested across Europe, albeit slowly, and our work shows ECs can contribute to them, where they exist. Meanwhile, ECs' distinctive capacity to develop demand-side solutions by design presents an untapped potential to accelerate the creation of sustainable energy systems.

This conclusion raises an interesting question: to what extent and under what circumstances should ECs strive to reduce demand and foster flexibility within their activities? Given the geographical variations of renewable-based energy systems and the predominant place-based nature of ECs, the answer is likely to be context specific and to vary over time. Nonetheless, it seems likely that demand reduction and increased demand-side flexibility will be important for ECs and broader energy systems across Europe - not least because of heightened expectations in many European countries to achieve carbon emissions reductions by electrifying heating and transport sectors.

Our work is not without limitations. The small sample size means any generalisations about the capacity of ECs to develop demand-side solutions needs to be treated with caution. EC activity is diverse and evolving. Our results, therefore, speak to our contemporary experience. Nonetheless, looking across the existing literature indicates the studied cases are representative of the wider field: they approximate a divergent area of activity at a time of unprecedented change within European energy systems. The results make an important contribution to how ECs are conceived and valued within current social science energy research. The results also raise questions for how national policy can be changed to support ECs as organisational innovations in European energy systems, as intended within the EU's recent energy strategy.

Future research is required to examine and expand upon the insights developed here. Research should examine the potential of ECs to reconfigure socio-material contexts of action through the creation of innovative socio-technical configurations. This could include: quantitative analysis of how addressing demand reduction and flexibility by design impacts outcomes; qualitative analysis of how existing policy and regulatory spaces (may) allow ECs to develop new socio-material contexts, as this is largely unknown; examination of the role and appetite of licensed suppliers to participate as partners in ECs; and analysis of the wider socio-economic conditions that impact, and in turn are impacted by, their development, including energy poverty. Such work will facilitate understanding of the changes to policy and market conditions required to realise the potential of ECs to develop demand-side solutions. Without further analysis and support from policy, ECs will likely struggle to achieve their potential, contributing innovative demand-side solutions to the creation of sustainable energy systems.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

### Data availability

Data will be made available on request.

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### Annex 1

Dominant energy representations identified across the nine case studies.

Energy representations (perceptions and practices)	Description	Indicative quotes from data
Energy costs	Energy costs in terms of monetary savings, energy affordability, financial benefits, and using more efficient technologies.	'We are a community of blue-collar workers; we are not engineers or something... we have limited knowledge about these things. So, our decision about joining this project might be 10 % related to this [environmental] awareness... but 80 % is about finance.' 'From the very first moment we realised that we had a 30 % saving on the bill, even if the reimbursement by [EC] is not immediate...' 'Four years ago, we built a detached house with a granny apartment and wanted to heat the house as cheaply as possible. That's how we got the PV system with the battery storage.'
Energy independence	Independence from traditional energy systems; access to energy through local installations and storage equipment.	'Our goal was to make this house as self-sufficient as possible, so that we would be independent from the influences of politics and the energy companies ...' 'I feel free to take advantage during the day of things that you would not normally do, because you go looking for savings, washing machines at night. Instead, you can easily do a normal daily life, do things in a natural way, we have completely changed the daily management, I feel more free to actually use the things we need...'
Environmental footprint of energy use	Environmental footprint of consumed energy: the importance of energy source and production. Maintaining everyday energy-related practices with reduced environmental impact.	'I am certainly very ecologically oriented, but I don't have to sit around with Birkenstock sandals. For me, it is important that I can live bright, warm, and comfortable. That is my premise. That the whole thing is also ecological and runs on the smallest possible footprint is a positive side effect'. 'We are trying to find different ways to make Solbyn more resource-efficient, ...trying to replace the energy we get from outside with things that we produce ourselves but also save energy and, in that way, reduce our footprint.'

## Annex 2. Summaries of case study problematisations featuring either demand reduction or demand-side flexibility

### Dalby Solby

Dalby Solby – ‘Dalby solar village’ – was initiated in the late 1970's by a small group of people to promote sustainable living. Influenced by Rachel Carson's book “Silent Spring” (1962), the group coalesced around the idea of creating and living in an ecological village. Researching, planning, negotiating, and building the village consumed the following 10 years, with construction of 50 apartments, a communal garage, laundry, kindergarten, and storehouse beginning in 1986, with the first residents moving in a year later.

Early discussions centred on the need for ecological lifestyles, the reduction of waste and resource efficiency with consensus emerging around the need for collective solutions and communal living. Some saw the solution as a single communal house in Lund. Others viewed the creation of a rural village next to an organic farm as appropriate. Others still, saw the solution within suburban living. Ideas were subsequently influenced by an architect who joined the group. An expert on energy efficient construction techniques, he introduced a range of ideas around developing a community from the bottom up. They included revised building designs to maximise passive solar gain, ideas for heat retention through internal heat absorbing structures, the use of solar thermal water collectors and domestic heat exchangers. Support for an eco-village was given further momentum with the support of Swedish housing development association HSB, who agreed, after some hesitation, to back the group providing both human and financial resources. Their support also required the upscaling of the project to 50 apartments in order to secure finance.

The village was designed to promote communal living with a variety of shared resources. Reducing the environmental footprint of residents whilst living in a resource efficient way has been central to the original idea of the Solby. The eco-village, designed from the bottom-up to avoid the need for energy wherever possible and to generate what is needed onsite, was presented as the means for realising and demonstrating sustainable living. This problematisation has remained ‘live’ since the Solby was established. In the 30 plus years since the first residents moved in, an energy group, currently comprised of approximately five members, has implemented further activities to reduce demand where possible.

### SO\_EN

The SO\_EN Social Housing was initiated in 2019 as a pilot project to test a new smart energy management system for equitable energy sharing in disadvantaged communities. Growing out of the Capacity project – a large-scale, multi-pronged urban regeneration and redevelopment project to transform Fondo Saccà, a derelict low-income neighbourhood in Messina – a variety of actors were involved in its design. Focal actors include the Community Foundation of Messina (Fondazione di Comunità) (FdC) who's primary interest is in research and development to fight social inequality and mitigate climate change, and SO\_EN S.p.A. an energy service company set up by the FdC in partnership with the European Society of Ethical and Alternative Finance, also a participant in the Capacity Project, with the aim of spreading a new energy culture whilst using technology to overcome energy poverty and marginalisation. Additional partners include ITAE CNR, who are interested in the design and use of innovative smart energy technologies; architects involved in the design of apartments; and social workers, who have the only direct contact with future residents and members of SO\_EN.

Key elements of the pilot were thought to include a sophisticated accounting platform – referred to as a social algorithm – that allows electricity pricing within the community to take households' socio-economic and health status into account, and innovative energy storage technology. Blockchain is foreseen as potentially playing a central role in the platform linking storage to use technologies. It is thought that this will offer a more secure and transparent means of exchanging electricity and managing the community energy system. A key innovation within the pilot is thought to be the energy management system, specifically the management of the storage system and its capacity to function independently of the grid. On this basis, reducing demand whilst increasing demand-side flexibility features as an answer to a higher-level issue: how to maximise self-sufficiency from onsite renewable generation and storage technologies. Multiple technologies are foreseen as playing a role reducing and flexing demand (e.g., energy efficiency systems, insulation and bio-architecture and batteries) creating an automatic system to save energy and maximise self-consumption so that members (end-users with vulnerabilities) can play a more passive role.

### Energy Local

The Energy Local (EL) model was conceived and developed by a small group of energy professionals in 2013. Having worked on smart grids and renewable energy projects, one of these professionals realised that many of the issues they were trying to solve from a technical point of view were fundamentally regulatory in nature. This led her to argue that generation and consumption of electricity from renewable sources was not being looked at in an integrated way, with systems inefficiencies present where renewable energy was generated but not used locally. For another founder, EL was a means to overcome emerging issues of network congestion whilst facilitating access to local resources for local people. The EL model was developed to address these problems and to make sharing energy fairer whilst achieving better outcomes for local communities and generators. Energy Local clubs were subsequently devised to link local renewable energy generators to local consumers.

Central elements of the visioned clubs included the introduction of smart meters within member households and the collection of half-hourly generation and consumption data. A ‘fair share’ algorithm was envisioned to equitably allocate consumption to demand in each half hour period, with the algorithm also being necessary for billing and for calculating net electricity consumed within the club, including how much was delivered to (if there was excess local generation) or consumed from the local network (if there was insufficient local generation). To pay for energy ‘shared’ within each club, founders proposed a ‘match tariff’, to be agreed between all club members to pay for local generation. To foster further time shifting of demand within each club the founders proposed using a fixed time of use tariff – varying throughout the course of a day according to national daily demand profiles - to supply all additional power required. Finally they suggested each club operate under a little known regulatory mechanism in close partnership with an existing licensed supplier to comply with electricity system regulations and operation. These ideas were tested in a trial of 48 households in Oxfordshire between 2015 and 17, and the first club was set up in Bethesda, North Wales, in 2017.

### sonnenCommunity

Sonnen was founded in 2010 by Christoph Ostermann and Torsten Stiefenhofer as a hardware company focused on home storage. It targeted existing solar PV owners who wanted to increase their self-sufficiency through onsite storage. The sonnenCommunity grew out of efforts to innovate the company's business model. Maintaining the company as a battery storage manufacturer was seen as a risk, particularly in the face of increasing competition from Asia. Instead of seeking a competitive advantage through innovating with hardware, the company began turning its attention to software. First, they sought to develop expertise in smarter battery operation through self-learning algorithms, before turning attention to connecting and controlling multiple independent units as one centrally controlled power plant. Analysing why people bought home storage systems, sonnen found that people generally seemed to want to take matters into their own hands, for example by investing in renewable energy assets.

The sonnenCommunity was subsequently launched in 2016 as a virtual community of all sonnen customers. The sonnenCommunity seeks to enable members to ‘declare independence’ and make traditional energy suppliers ‘obsolete’ by covering 100 % of their electricity needs through a

combination of self-consumption and community supply coordinated as a 'virtual power plant'. To achieve this in practice sonnen sought to link and control the decentralised and privately-owned generation and storage units of members through cloud-based software. For the company, the sonnenCommunity not only presented a new service offering to customers, but also provided a new business opportunity: supplying a range of ancillary services to national and potentially local energy markets using the domestic batteries at its control.

### Annex 3

Central BM elements of case studies.

Case study	Value proposition	Value creation and delivery	Value capture
Buurtmolten Herbaijum	Collective consumption of local wind energy by residents	Key activities: energy generation and sale, management, and billing, Key resources: expertise and management Partners: established supplier	Cost: leasing of land, capital installation Revenue: sale of electricity, generation subsidies, members fee
Dalby Solby	Creating sustainable lives and places through individual and collective solutions	Key activities: design, survey and installation of energy efficient and renewable generation kit Key resources: expertise, time, capital Partners: installers	Costs: capital investment. Revenue: energy savings, sale of surplus electricity
Energiecoöperatie Zuiderlicht	'Energy generation for everyone'	Key activities: project management, asset ownership, share raising, Key resources: expertise, trust Partners: building owners, established supplier	Costs: project development, management and outreach activities. Revenue: electricity sales, customer retention payment from partner supplier, generation subsidies
Energy Local	Creating fair prices for generators and consumers	Key activities: agreeing 'match tariff' annually, allocating flows of power, shifting timing of demand Key resources: knowledge, expertise Partners: established supplier	Costs: associated with initial set up, management Revenue: membership fees
ERiC Project	Expert advice and support to install residential solar PV systems	Key activities: advice, training, and creation of purchasing groups Key resources: expertise Partners: PV supplier, engineering consultancy	Costs: time, training. Revenue: one-off membership fee to join purchasing group, 5 % share of revenue from engineering consultancy
GEN-I Jesenice	Collective action for reduced costs and environmental impact	Key activities: design and installation of solar PV and heat pump systems, financing, billing Key resources: expertise, knowledge Partners: established supplier	Costs: capital expenditure, maintenance. Revenue: householder savings
Project Z	'Regional, sustainable energy autarky'	Key activities: managing electricity flows between members Key resources: expertise, knowledge Partners: blockchain developers, established supplier, and DSO (all in house)	Costs: R&D costs Revenue: mark up on traded power, sale of additional power via established supplier, affiliate marketing
Solidarity & Energy Social Housing (SO_EN)	Affordable and fair power,	Key activities: design and build low energy housing, balance supply and demand behind a single meter point, operation of 'social algorithm' to allocate costs Key resources: expertise, knowledge, capital Partners: Energy service Company, architects, social workers, research organisations	Costs: capital installation and R&D. Revenue: service contracts
sonnenCommunity	'Clean, reliable and affordable energy for everyone'	Key activities: coordinating batteries as a virtual power plant to supply members and provide grid services Key resources: technical expertise, data management, Partners: none	Costs: R&D and operational overheads. Revenue: domestic energy contracts, provision of flexibility services to power systems

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