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A capability approach to smart local energy systems: aiming for 'smart and fair'

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Abstract

This paper describes early experience of using a conceptual framework of "capabilities" to understand the propensity of actors (households, businesses, flexibility providers) and communities to participate in and benefit from a Smart Local Energy System (SLES). Having outlined some basic features of capability theory and examples of its application, we offer a description of the SLES concept, then outline how a 'capability lens' can be applied as an analytic tool in designing policies and actions that are sensitive to issues of energy equity. We do this through applying an elaboration of the capability lens developed by the Centre for Sustainable Energy to two smart grid opportunities under consideration in "Project LEO" a major demonstration of prototype SLES mechanisms and market arrangements underway in Oxfordshire, UK: Vehicle-to-Grid charging and domestic Demand Side Response from small scale applications (e.g. heat pumps, smart appliances) connected at the grid edge. There is a discussion of how capability to adopt these systems has implications for differential access to markets for flexibility and therefore impacts on energy equity. We then argue that a capability lens can be applied not only to individuals, households or organisations, but to communities and systems and considers how inequity might be addressed in terms of actor, community and system capability.

Introduction

Smart Local Energy Systems (SLES) are a relatively new concept with a focus on the use of distributed resources in a locality, with the aid of ICT, to manage increased generation of low carbon energy and new electricity demands from electrification of heat and transport connected at low voltage levels at the "grid edge". Integral to SLES are trading platforms where energy services that help the distribution network operate can be auctioned, procured, dispatched, verified and settled and where peers can trade energy, power and electrical capacity. Large-scale actors have participated in markets for energy services for many years, but with the advent of distributed renewable supply and storage, smart metering and cheap internet connected monitoring and control systems, participation is now open to small-scale domestic and business customers, at least in theory. This means the formation of new relationships between actors who are learning new roles, for which they will need capabilities: the ability, suitability and willingness to contribute to, and benefit from, local energy systems. Communities too must learn to act collectively and in new ways if they are to fully benefit from the SLES opportunity. Required capabilities for participation by individual, organisational or community actors fall into domains: a) technical (e.g. possession of a generation asset); b) economic (e.g. financial resources to invest in assets; c) lifestyle/operational (e.g. ability to shift demand without detriment); d) skills and motivation (e.g. digital skills); e) social capital (e.g. sharable skills and insights, normative approval). The energy system as a whole must also be able to host or integrate a SLES by possessing capabilities such as a conducive planning, policy and regulatory environment, market platforms where services can be traded and sufficient actors of particular types to supply liquidity, competition and necessary services.

These actor, community and system level capabilities will be distributed unevenly, with the likelihood that actors and communities with fewer financial resources or less ability to take risk will be less able to access benefits from SLES and may be 'left behind'. Similarly, where the local energy system or distribution network does not have the requisite capabilities to host a SLES, that part of the network will not fully participate in the energy transition. Therefore absence of requisite forms of capability at all levels can be understood as issues of equity and fairness where interventions may be required to either reconfigure actor capability or system capability or both. Alternatively, the SLES offer itself must be reconfigured to meet local capabilities if unfair outcomes are to be avoided.

The application of a capability framework to evaluation *and development* of a SLES is an entirely novel approach. This paper offers an elaboration of the CSE capability lens in proposing actor, community and system levels of capability and in extending "actor" capability to cover businesses and other organisations as well as households. We test the success of this and the degree to which a capability approach offers new insights into energy equity and policy development through evaluation of the adoption of two key SLES technologies: Vehicle to Grid technology and Demand Side Response at the low voltage (LV) level. Both technologies are being deployed in Project LEO, a major demonstration project funded by the UK government's Prospering From the Energy Revolution (PFER) programme which is developing prototypes for SLES in Oxfordshire, UK.

Theoretical roots of a "capability" approach

The concept of capability as applied to human needs was introduced by the economist and philosopher Amartya Sen. It offers a way of framing needs that relates to what people are able to do as well as to what they have, taking into account social arrangements as well as individual capacities – for example, the right to speak freely, vote and gain access to public goods as well as the capabilities gained from personal health, strength, temperament and earning ability (Sen 1999). As it stands, the basic concept is open to many interpretations and applications. It has been developed and applied more specifically, for example by Martha Nussbaum (2003), who argued that some capabilities are more important than others and must be protected as rights: these she defined as life itself, bodily health and integrity, freedom of the mind, ability to form emotional attachments, ability to reason, ability to live in relation to, and with concern for nature; ability to play and to control one's environment in terms of having a political voice, property rights, and rights as a worker.

This idea of a set of fundamental capabilities which enable human development and access to systems of welfare has been elaborated and used in other contexts and resonates with other frameworks which try to explain the various dimensions of human capacity to change behaviour, access benefit or to adopt technology. A recent example is the COM-B model (Michie et al, 2014). The framework, based on a meta-analysis of behaviour change initiatives in the health sector, proposes that an individual's Capability, Opportunity and Motivation (described as "sources" of behaviour) interact to generate Behaviour. Capability refers to an individual's psychological and physical capacity to engage in the behaviour (the required knowledge and skills - both mental and physical); Opportunity refers to all the factors that are external to the individual that make the behaviour possible. These could include social norms for the behaviour and the technical and material infrastructure in which practices are embedded and which enable some behavioural choices whilst barring others. Motivation refers to all those cognitive processes that energize and direct behaviour— conscious goals and attitudes and also unconscious drives and wishes. This framework has been used to understand adoption of innovative energy behaviours, for example, it has been used to structure an evidence review of capabilities that encourage more energy conscious behaviour in the workplace (Staddon et al, 2015).

Another capability framework proposes the idea of "carbon capability" (Whitmarsh et al, 2009). This describes the broad capabilities of a citizen able to respond effectively to the climate crisis, both personally and politically i.e.it identifies an individual's ability and motivation to reduce emissions within the broader institutional and social context. Three dimensions of carbon capability are identified: (1) cognitive (knowledge, skills, motivations, etc.), (2) individual behaviour (e.g., energy conservation) and (3) broader engagement with systems of provision and governance (e.g., lobbying, voting, protesting). This last dimension is particularly important because it points to the need for system change (to enable personal behavioural change) and assumes that the individual has a role (albeit acting together with others) in bringing about system change. We could argue that in order to transition to a low carbon energy system, political systems and governance must be in place which allow the voices of people, communities and organisations to be heard and actioned.

Most recently, the Centre for Sustainable Energy have produced a "capability lens" as part of their research programme exploring dimensions of a socially just energy transition, "Smart and Fair". Their "capability lens" is a framework to understand the sorts of capabilities and attributes likely to be required in the transition to a smarter energy system and how these distribute across the household population (CSE, 2020). This work is highly relevant to approaches to engagement, trial design and evaluation under development in Project LEO.

Smart Local Energy and capability

Energy systems are networks connecting people and their activities with demand, supply and storage technologies. We start from the proposition that they are as social as they are technical. What is more, they are evolving in directions that are more socially as well as more technically complex. The most striking example of this is the spread of small-scale electricity supply, but we could also cite the growth of heating and cooling networks, increased reliance on demand response to improve electrical system reliability, and the adoption of electric vehicles with their enormous potential to act as mobile batteries. These require not only new technologies but new commercial, legal, technical and social configurations and rules.

Smart local energy systems (SLES) are a relatively new concept, with no fixed definition. At this early stage of development, many questions about their nature and outcomes stand open. Ford et al. (2021) provide a helpful overview of SLES, envisaging them as standing in the 'regime' territory of a multi-level perspective. The regime includes interacting 'smart', 'local' and 'energy system' elements, which will be developed according to local requirements and inputs along with much wider influences and pressures: social, technical, financial and environmental. Relevant to this paper are questions of *direction* (which will involve prioritising some goals and processes over others); the nature of *demand* for SLES; *policy coordination* across scales*;* and *reflexivity,* the need for governance and regulation that supports agile learning and adaptation (ibid.). Note that the SLES differs from the older concept of community energy, with more emphasis on market and technical elements (Devine-Wright, 2019).

Energy transition is generally seen as benign, but it is not hard to see that there will have differential impacts on welfare. Even if transition from centralised fossil-fuel-dependent to decentralised renewables-based systems delivers all the projected indirect benefits of low-carbon energy services and cleaner air to all, the more direct benefits are likely to gravitate to people who own supply, demand and storage assets and who are able to use them to generate energy services and income for themselves and their dependents. There will need to be a conscious effort to develop SLES in such a way that participants in the system, and the system itself is capable of generating benefits in an equitable way.

A disturbing comparison can be made between Sen's analysis of the causes of famine and the potential for energy poverty in a post-transition energy system that relies on smart technology. Sen argued that the Bengal famine of 1943, for example, was not caused by lack of food per se, but by a complex of factors that led to starvation: unemployment and low wages, rising food prices and poor distribution. Panic buying by those who were capable of accessing and paying for food only made the situation worse for the rest. It is conceivable that disadvantaged people in a zero-carbon smart system, producing adequate electricity that was theoretically adequate for all, could still be progressively disadvantaged through lack of access to generation or storage assets, low-quality housing and l, limited social networks, low levels of digital access and literacy, and lack of ability to participate in new energy markets. The 'smarter' or more sophisticated the system, in such a scenario, the further they would be left behind.

Through a capability lens, poverty can be seen as an inability to participate fully in society while equity can be seen as the ability to access benefits in life on an equal basis to others. Building on recent work on capability in energy systems and on the experience of a major SLES demonstrator project, we argue that a capability lens offers a productive means of analysing SLES and also a tool for planning and evaluating pathways out of poverty and towards energy equity.

Actor and system capability

The factors determining support, acceptance and participation in a smart local energy system can be understood as operating at various levels, including the capability of individual actors in the system, of communities, and of the overall system to host a SLES.

Actor capability.

Individual stakeholders or actors in the system may need particular technical capacities, skills, knowledge, financial and social capital and motivation to participate in the SLES or to take benefits from it. They should also be at the "right" stage of their development as organisations or as households where participation in a SLES makes sense (Fawcett, 2014). There will be linkages and correlations between socio-economic, lifestyle and personal factors and the capacity to own or operate household equipment and control systems allowing participation in local energy systems. There will also be linkages between the capacity to make behavioural and lifestyle changes and socio-economic and technical characteristics of the home. Drawing on CSE's "Smart and Fair" framework (CSE, 2020), we group types of capability into the following domains:

Technical capability of building or site
The suitability of a building in its location to participate in the SLES. This includes consideration of whether the building structure and building/plot layout is capable of retrofit for behind-the-meter generation (solar or batteries), energy efficiency measures (e.g. insulation to optimise heat pumps), or low carbon heating systems. The location of the building's connection point to the local network will also affect its capability to participate in the SLES: is its electricity supply connected to network assets which are at or near their thermal thresholds?

Technical capability of the power-using equipment and control systems within the building or site
This refers to technical characteristics of equipment within the building: whether appliances can be remotely and automatically controlled and/or whether equipment has the capacity to be retrofitted with controls. Is there a smart meter? A smart hub? The characteristics of power-using equipment in the household or business and how it is controlled will influence the building's demand profile. Digital capability

Digital capability
This describes the hardware and connectivity, skills readiness and level of digital engagement of a household or organisation to enable them to participate in and benefit from opportunities. It will include broadband access and quality, plus familiarity and competence with smartphones and computers, and ability to keep up with software developments. If someone does not have this capability as an individual, they will need access to people who have.

Financial or economic capability
This refers to ability to invest in technologies or training, take some level of financial risk or access capital or funding.

Social, personal, or organisational capability
Actors will need to be motivated to participate in a SLES and have the knowledge base, cognitive and practical skills, social connectedness and awareness to understand and value the benefits of participation. This applies equally to households and organisations, where organisational culture, practices, management systems and indeed the attitudes and knowledge of key individuals will be important in influencing take-up of the opportunity to participate in a SLES (DECC, 2011). Community-level social capital, the product of relationships within a locality and the resources that individuals and organisations bring to a community, will be a crucial element in its capability to host and participate in a SLES.

System capability
At present we identify three principal attributes of system capability:

- The structure of a local market for energy services. What services are required, the actors and assets who will provide them, the platforms on which trading will happen, the market rules for trades etc
- The regulatory, planning and policy context for system development. This will strongly influence the value of flexibility services (for example, the value of avoiding investment in network reinforcement), national and local political support for SLES initiatives and the planning environment in which they can be developed.
- The distribution network characteristics, notably the parts where it is under stress or is likely to be stressed in the near future: this will affect the assessed value of flexibility services, and the capability of the network to accommodate new generation and demand.

Market structure
Early experience suggests that a SLES can only be successful if there is a mix of actors including:

a) owners and developers of assets capable of supplying energy services (these could be households, schools, communities, businesses, energy supply companies)
b) value creators and facilitators (aggregators, operators of third-party market platforms)
c) procurers of energy services (the DNO, the ESO, energy suppliers, generators involved in peer-to-peer trades of power capacity
d) investors
e) policy makers and planners, local authorities, local enterprise partnerships

Relationships between actors can be understood in this market context as exchanges of value where value can be financial, environmental or social. Business models and value propositions will develop to formalise these relationships and exchanges of value, and the emergent behaviour or qualities of the system as a whole must create a context in which SLES practices and operations can survive and thrive. There must also be sufficient numbers of each type of actor. For example, only a small number of aggregators in a SLES may be required but there should be many flexibility providers able to flex their demand in response to network needs so that:

a) a range of network services can be provided: kWh energy supply to kW power supply to voltage maintenance.
b) the local energy market is liquid, competitive and flex can be provided as necessary right across the network.
c) the market is resilient and not reliant on a small number of flex providers who may not be able to deliver contracted services as required.

Policy and regulation
The Distribution Network Operator plays a critical role in managing the system infrastructure and in hosting IT infrastructure and market platforms that allow market actors to trade energy services amongst themselves (e.g. peer-to-peer trading of power supply capacity) and with the DNO itself (e.g. flexibility services to manage peak demand). The policy governing DNO operation are key to system viability and to its capability to produce socially just outcomes. The quality of the relationships between different actors in the ecosystem (and indeed whether any relationship exists at all) is driven by the regulatory and policy context and the characteristics of the regulatory institutions and their norms ("ways of doing things"), business practices, rules of thumb, organisational cultures etc. Policy and regulation are vital considerations in three domains related to the operation of energy systems: the built environment, transport, and communications. With the spread of smart technology into more and more areas of life, access to fast, reliable broadband has become necessary for full participation. This has been illustrated forcefully during the Covid-19 pandemic, for home schooling and home working.

Network state
A critical feature of the system's capability is the state of the network. How capable is the local network of accommodating new connection of intermittent generation and new sources of energy demand, primarily from new housing development and trends in electrification of heat and transport. Network state will drive the need and hence the market for specific network services to be delivered at specific points in the network.

Applying system and actor capability lenses to SLES offers

To illustrate the application of the capability lens in a SLES, and its value in identifying who can take part, on what terms, and with what results, we now look at the capabilities of actors and systems needed to adopt two specific smart energy system offers. This general approach draws on the framework developed by CSE's offer-profiling tool (CSE, 2020).

1. Vehicle to Grid technology. This includes Vehicle to Grid capable vehicles and the specialised Vehicle to Grid chargers.
2. Small scale, aggregated demand side response. Technologies to create energy services from small amounts of flexibility available at the "grid edge" e.g., demand side response services derived from heat pumps and retrofitted controls on storage heaters, water heaters and other appliances.

Electric Vehicle-to-Grid

Vehicle-to-Grid (V2G) technology is still in its early stages of development but offers many possibilities for SLES by virtue of its ability to create flexible demand and generation services. V2G can take charge from the grid or from a site (e.g., where there is behind-the-meter generation such as a rooftop solar array), store the energy for a limited period and then discharge, either back to the site or to the local network. Optimising these charge and discharge cycles allows the creation of network services, the ability to take advantage of time-of-use tariffs (based on wholesale markets for electricity) and to charge at times of low carbon intensity of grid supply and discharge at times of high carbon intensity. Connection of V2G at low voltage level does not limit it to DNO services. In the UK, V2G using domestic vehicles connected at the low voltage level have begun supplying energy services to the National Grid Energy System Operator (ESO) in the Balancing Market. Hence there are multiple ways of working with V2G technology to create different value propositions. These are not only economic, as V2G can also deliver value through:

a) Facilitating greater network resilience,
b) Achieving net zero at individual household or community levels,
c) Creating wider benefits to society by enabling a grid that is better able to function with intermittent renewable generation,
d) Extending battery life in electric vehicles through enhanced battery management.

However, installing V2G is not without its issues:

1. V2G charging infrastructure can be extremely expensive to retrofit to sites if the local network needs to be reinforced and streets have to be dug up.
2. V2G charging for best results from the network point of view may not always coincide with vehicle-owners' travel patterns and preferred charge and discharge times.
3. Policy and regulation have not entirely caught up with the need to provide a framework that encourages and enables V2G operations. Current DNO policy for connection of V2G to local networks does not always recognise the flexibility it can bring. Therefore, it can be viewed as a technology that could exacerbate network constraints rather than resolve them.
4. Only certain vehicles (and therefore charging standards) are V2G compatible.

Aggregated small scale grid edge Demand Side Response

Many of the big electricity users in our homes can be designed to flex their energy demand. Smart appliances such as washing machines, refrigerators and electric storage heaters are already in production, whilst heat pumps are also now available which have internet connectivity and control and which have been proved to be capable of providing flexibility services (DELTA, 2018). The control systems and connectivity required for smart operation can also be retrofitted to some appliances. For example, VCharge have developed a control system which allows conventional storage heaters to be controlled via the internet to optimise charging around a day ahead Time of Use tariff.

Automation and internet connectivity are critical to the technical viability of aggregated DSR where thousands of small assets are coordinated to balance supply and demand at the local level. Control systems allowing automated interaction between thousands of small-scale assets and market actors (aggregators) and market platforms are also critical to the financial viability of flexibility created in this way by ensuring that transaction costs are minimal. Control and decision-making systems (little “black boxes” of electronics embedded in the intranet of a home or business) can be connected directly to the internet or operate via a gateway device connected to a smart meter. There are linkages between these systems allowing grid edge flex provision and wider “smart home” technologies. For example, smart thermostats such as Google’s Nest are already being used to allow domestic heating and cooling systems to participate in markets for flexibility in California, under the control of an aggregator. This technical capability to flex demand in small power loads requires an aggregator to coordinate the pool of assets. Aggregators can also absorb some fixed costs (e.g., from smartening equipment and installing control systems), manage some risks and provide analytics such as forecasting demand and developing strategies to head off network difficulties. However, facilitating this kind of flexibility is not without its issues. These include:

1. Ownership of innovative smart appliances, heat pumps and storage systems (including electric vehicles) is likely to be concentrated amongst higher-income and tech-savvy groups. Other groups may not be able to take advantage of these technologies until costs come down and secure supply chains are established.
2. Some groups will not be able to flex energy demand without possible detriment to their welfare. For example, older and more sedentary people are at greater risk of stroke or cardio-vascular problems if the indoor temperature drops below certain thresholds. A heat pump under automated control to provide flex services could conceivably turn off and drop temperatures to unhealthy levels during a flex event.
3. Increasing penetration of smart technologies into the systems supporting daily life raises concerns around data privacy and the increasing levels of control and influence that big technology companies have in daily life.
4. Putting in place the technological and commercial systems to allow small slivers of flexibility to be auctioned, procured, dispatched, verified and settled, is likely to incur significant transaction costs if technological solutions are not found. There is a danger that these may outweigh the value of the flexibility itself. Therefore, the capability to create grid edge flexibility with minimal transaction cost is critical.

System and actor capabilities for integrating demand side response and vehicle to grid technology in SLES are shown in the tables below.

<table>
<tr><th></th><th></th><th>Vehicle to Grid</th><th>Small-scale aggregated Demand Side Response</th></tr>
<tr><td rowspan="5">Actor capabilities</td><td>Site / building and curtilage
Building energy efficiency
Technical capacity for measures to be installed.
Layout and orientation of the building and curtilage</td><td>The site must have space for secure parking of EVs close to accessible chargepoints.
Installation of V2G chargepoints can be disruptive and expensive where hard standing must be dug up or where the local electricity supply system must be reinforced. Ideally the building will be capable of installation of V2G technology without excessive cost</td><td>Heat pumps work optimally when they are installed in reasonably well-insulated buildings. Also flexibility provided by heat pumps which does not compromise comfort thresholds is only possible for longer DSR events (longer than 3 hours) in reasonably well insulated buildings. Therefore, where flexibility using heat pumps is sought, the building will either already be, or have the capacity to become, well insulated. Heat pumps also have certain internal and external space requirements.</td></tr>
<tr><td>Energy technologies and usage
Smart metering
Smart controls
Space heating and cooling appliances
Water heating appliances
Refrigeration appliances
Energy demand profile
Solar PV
Electric Vehicle
Battery</td><td>Only a small number of vehicles are V2G compatible. Hence the V2G customer must adopt specific vehicle types. Optimising the benefits of V2G around discharging during peak times is only compatible with certain driving patterns. Ideally V2G EVs should be connected to the charger ready to discharge during the evening peak (4 to 7 pm) and be connected for the weekend. This tends to mean that V2G is well suited to ‘return-to-base' fleet vehicle applications. V2G can work well with behind-the-meter generation such as solar roofs. This improves the environmental value proposition. V2G charge and discharge must be monitored with a smart meter.</td><td>The actor must be in possession of smart appliances, smart water heating, smart heating and cooling systems and smart storage.

This form of DSR will require a smart meter to be installed, to verify that DSR has taken place. DSR delivered through TOU tariffs will likewise require a smart meter to be installed to calculate the energy bill. Smart meters may also be used in the control system for smart appliances, either through the auxiliary load control switch or through a gateway device. A smart meter is also necessary to monitor and verify the timing and volume of the flex event.</td></tr>
<tr><td>Financial
Household disposable income or financial resources
Tenure type, length, security
Mortgage and lease conditions
Willingness to invest or borrow.
Investment rules: IRR and payback</td><td>EVs and associated charging infrastructure are considerably more expensive than fossil fuelled alternatives. Customers for EVs will need to be able to borrow significant sums or have substantial financial resources.
Where EVs are introduced into commercial buildings, lease agreements must allow installation of V2G infrastructure.</td><td>Smartened household equipment and appliances are likely to be more expensive than standard alternatives. Batteries and heat pumps are significant costs.
Heat pumps will only perform optimally in well-constructed, reasonably well insulated homes. Therefore higher income owner-occupiers will likely have financial resources to invest in insulation and/or large heat pumps and to be resident in buildings with requisite good fabric standards.
Those in private rented accommodation are very unlikely to be able to adopt this technology. Those in social rented housing have much better likelihood of the landlord installing smart-enabled technology.</td></tr>
<tr><td>Technological readiness
Smart phone
Digital capability
Internet connectivity</td><td>V2G users control charging schedules via an app. Customers must be comfortable using the app and understanding how to get the best out of their V2G system</td><td>Early owner occupier adopters of smartened technology enabling DSR are likely to be highly digitally capable. However, the principle behind its operation is ‘fit and forget’. The business models for DSR do not work unless transaction costs are very low and interaction with the grid is automated. Hence the digital capability of DSR providers does not necessarily need to be high, other than capability to override the system occasionally.</td></tr>
<tr><td>Personal, social, cultural
Knowledge and skills
Values</td><td>V2G technology is still under development. Markets for the flexibility services that it can provide are non-existent or not widely available. Consequently, the business</td><td>Minor shifts to energy demand profiles must be able to fit with lifestyles and practices, without detriment to welfare.</td></tr>
</table>

	• Good health • Attitude to risk • Social capital • Social norms • Trust in provider	case for investment in V2G EV may be marginal. Therefore customers should have the capability to absorb financial risk and to recognise non-financial benefits. They will need to have trust in the system provider and back-office services. Knowing others who have taken up the offer can build trust and understanding of how the service can fit with lifestyle. This includes overcoming anxieties about not having sufficient charge to make essential journeys.	It is also important to recognise how a service offer fits with householder priorities and values (e.g. an emphasis on reliable warmth or on economising, privacy, self-reliance)

		Vehicle to Grid	**Aggregated Demand Side Response**
System capabilities	**Market structure** • Market platform • Local market for flex services • (peak and fault management) • National market for flex services (balancing mechanism, capacity market) • Market for peer-to-peer services	V2G requires an aggregator able to stack and trade value from the various services that it can provide, e.g. national balancing services to ESO but also local DSO flexibility services. Hence the local energy system should ideally interact with a number of market platforms and markets. V2G, like all battery systems, is good at providing some specialised services such as provision of reactive power. This is particularly valuable in parts of the network where there are high levels of electrical resistance - at the LV level in general and particularly in long cable runs in rural areas. The system must be capable of rewarding these services.	DSR with small, distributed sources of flexibility requires the services of an aggregator. There must also be local energy market demand for flexibility sourced at the grid edge. The value to the householder from providing flexibility is likely to be very small. So the market must be structured so that there is minimal transaction cost, which would otherwise further erode the revenue stream. This has major implications for the business model of the aggregator and the operation of financial and technical systems used to create, sell, dispatch, verify and settle flexibility. Only certain types of business model and company structure will be able to operate in this market.
	Policy, regulation, planning • Regulations on DNO pricing for usage of network • Services supplied by DNO – constraint map, data, information. • Local DNO connections policy • Local area energy planning services • Local and national carbon policy • Local planning	It is difficult for V2G suppliers and aggregators to build business models and create value propositions without knowing the location of network constraints and the value of flexibility in specific parts of the network. The DNO and local authority planners should develop this information and make it accessible. DNO policies can pose an obstacle to connection of V2G in parts of the network where there is a network constraint. The flexibility that V2G offers is not always recognised. Evidence suggests that the worst-case scenario is always assumed i.e., that the V2G will charge from the grid at times of peak demand and also discharge at maximum capacity when the local grid may already be at capacity. Hence the system should have connection policy that facilitates V2G wherever possible.	Recent UK revisions to charges for use of the network undermine the business model for installation of behind-the-meter technology (which reduces energy drawn from the grid) because charges to customers for maintaining the grid will now be based on the capacity of the customer's connection (i.e., they will be fixed) and no longer on the basis of volume of energy consumed. This is considered fairer by the UK regulator, who argue that customers who are not able to afford behind-the-meter technology will not be compelled to pay more for network maintenance than those who have the technology. Local Area Energy Planning functions held by the local authority and the DNO must ensure that attempts to secure this kind of flexibility set financial and other barriers to access as low as possible
	Network state • Existing network constraint • Forecasted network constraint.	V2G offers the means to tackle network stresses via delivery of flexibility services. Hence V2G installation as part of a SLES is facilitated where there is a market for flexibility services, by virtue of existing or forecasted network constraints which are most cost-effectively dealt with via flexibility rather than reinforcement.	The network status must require the kinds of energy services created by local DSR sourced from the grid edge.

Discussion

Actor, system and community capability

Application of the capability approach in Project Leo has found that analysis of the capability of individual households or businesses can be usefully supplemented with analysis of the capability of the energy system itself to provide a socio-technical, regulatory and economic context in which a SLES can become embedded and ultimately replicate and thrive. However, conceptually, there is also an intermediate level of capability which seems to straddle actor and system domains that could be termed, "community capability". This refers to the capabilities that emerge when actors within a community of place coordinate their activities to create new capability which is not (easily) available to actors acting as individuals. Just the ability of actors within a community to talk to one another about the merits of an energy innovation (such as a device that could automatically control electricity demand to create energy services) has been shown to increase the likelihood of adoption of particular innovations fourfold (McMichael and Shipworth, 2013). Interpersonal communication is enabled when a community has a relatively dense network of social relationships. This is sometimes called "bonding" social capital. Hence, some communities with higher bonding social capital are probably more capable of adopting energy innovations and coordinating their assets than others (Darley and Beninger,1981). There is also an equity dimension in the distribution of various forms of social capital. For example, it has been found that impoverished communities have lower levels of bonding social capital than higher income ones (Larsen et al, 2004). Also that skills and resources that could be shared across a community in order to achieve communal objectives are associated with communities with relatively high incomes and levels of education. These types of capability are sometimes harnessed by community energy projects. Examples of relevant capabilities would include a community's collective wish, financial and planning skills to site solar arrays or community scale batteries on or in community buildings such as schools or blocks of flats. This social capital capability would also need to be complemented with the technical and physical capability of having appropriate roof space. A second example would be a community coming together to fund a community asset from sale of their aggregated flexibility. This is an interesting possibility where the value of flexibility to an individual actor may be so small as to be inconsequential or perhaps even negative once transaction costs are factored in. But, when aggregated, the value becomes enough to create change. This idea has been mooted in Oxford in relation to funding the installation and maintenance costs of a publicly accessible V2G chargepoint.

The capability lens works for businesses and organisations as well as households

In applying the capability approach, we have found that the idea works equally well in the non-domestic sector e.g., with SMEs or public sector organisations. These too can be described as having technical, financial, intellectual, cultural and social capabilities. Equally, those that are lacking in certain capabilities may not be either willing or able to participate in smart local energy systems and are therefore at risk of being left behind in the energy transition. As for domestic actors, in order to catch up either the system or SLES offer must change or organisation itself must adapt by growing its capabilities. The review of capabilities required to adopt V2G suggests that the technology is best suited to organisations running fleets of particular V2G-compatible vehicles (primarily the Nissan Leaf) and where the vehicles are used in a regular pattern of being driven during the day with a return to base around 4pm. This allows reconnection and discharge of remaining power in the batteries into the local network during peak times between 4 and 7pm – thereby alleviating peak time stress and providing a network service. The V2G system is also more expensive than conventional EV charging technology. The case for investment in the technology is also based on inherent uncertainties– e.g., the value of flexibility at the site in one years' time. This means that only certain types of organisation with financial resources and the ability to absorb certain levels of risk are likely to adopt the technology at this time. The capability to absorb risk and to have larger financial resources is generally associated with larger organisations. Struggling SMEs are therefore less likely to participate in the V2G offer and consequently to reap the benefits of V2G flexibility sales. This scenario suggests there are energy equity issues amongst organisations as well as in the domestic sector.

Capability, the actor network and the sociotechnical "ecosystem"

The capability approach is theoretically aligned with a sociotechnical lens on energy systems which sees system activity as the outcome of the actors' interactions with social, economic, political, communications and material infrastructures (e.g. Eyre et al., 2018). The quality of those interactions will be determined by actor and system capabilities; therefore capabilities should also be seen in social, economic and technical terms. A good analogy for the energy system is an ecosystem: each actor occupies a niche in the ecosystem and, to survive and replicate, must offer something of value to the system, an ecosystem service. In return, it will receive something of value, allowing it to continue in existence. The nature of the service depends on the actor's role (or niche) within the system and the 'laws of the jungle' which determine the directions in which the system evolves. An actors' capabilities are a function of their niche within the ecosystem and the system's capability which, in the ecosystem analogy, can be understood as the "laws of the jungle". System capability can be grouped into four domains:

1. Regulatory and policy context for local energy systems including the planning system.
2. Material: physical infrastructure, structure of the distribution network including physical and temporal location of network constraints, specifications of equipment, design of buildings.
3. Economic and market factors: energy services sold on the local energy marketplace, supply chain characteristics, value propositions, market rules. Investment rules e.g. IRR thresholds
4. Social, cultural and political: trust in governance and political systems, organisational 'ways of doing things', social norms (including right of access to affordable energy services), codes of practice.

Whether a local energy system can survive and thrive will be determined by the 'friendliness' of the system to SLES approaches and the extent to which the web of value propositions linking one actor with another is viable and desired.

Capability to participate in Smart Local Energy Systems and Local Energy Markets

Application of the expanded capability lens (i.e. to cover both actor, community and system capability) to two socio-technical subsystems under investigation in Project LEO (V2G and grid edge DSR) has shown that this is a useful analytic approach that suggests what characteristics and capabilities enable an actor to adopt a specific SLES offer or opportunity and thus identifies whether this may have implications for equity of access to participation in the SLES. Also, the approach allows identification of interventions that could change either system or actor capability where equity of access is not found. For example, the DSR offer requires that participating actors must be capable of affording and using smart equipment allowing automatic control and transactions with a market platform. This is essential to drive down transaction cost, which would otherwise destroy a business model geared around capturing hundreds of thousands of slivers of grid edge flexibility. Households that don't score highly on the various indices of capability for owning and operating this equipment are more likely to need an intermediary to equip the home and train residents in using the equipment and in capturing benefits from the system. However those using an intermediary to gain market access will effectively forfeit some portion of the value of their flexibility because use of the intermediary service has a cost. Further, in an unequal society, people's possession or access to these capabilities will be unevenly distributed across different socio-economic, demographic, geographic, and cultural groups. Low-income households and households affected by other forms of social disadvantage will be less likely to own or have access to the smart equipment and therefore less capable of accessing the benefits of SLES and participating in local energy markets. Therefore, in tackling an inequity in securing access to the local energy market through use of an intermediary, another inequity is potentially created – less benefit will flow to the groups that need it most because the intermediary service must be paid for. A key challenge for Project LEO and for SLES in general will be creating a marketplace and local energy services where a range of actors (including aggregators and other intermediaries) are able to operate with business models and value propositions which work with demographic groups with low levels of the specific forms of capability ideally required. But there is a balance to be struck. If the transaction costs of widening access to as many as possible becomes too high, value propositions are undermined, business models become unviable, and take-up of the offer becomes stymied. Therefore, to ensure that access is as widespread as possible, there will need to be a diverse mix of market actors operating with different value propositions, some of which will not be structured around optimising financial returns. A not-for-profit community aggregator is one such idea (Carbon Coop, 2018).

Capability, poverty and energy equity

Bouzarovski and Petrova (2015) argue that domestic energy poverty or deprivation results from 'ineffective operation of the socio-technical pathways allow for the fulfilment of household energy needs and… is best analysed by understanding the constitution of … energy services in the home' (ibid, p31). They set out 'vulnerability factors' such as lack of access to energy carriers, inability to shift from one fuel to another, affordability and lack of knowledge about how best to use energy or sources of assistance. Thus energy vulnerability can as a multi-faceted lack of capability to gain adequate energy services. Middlemiss and colleagues bring together the concepts of capability and energy poverty in their analysis of the UK situation. They set out the complex nature of energy poverty, something that maps well onto the diversity needs, functions and connections associated with capability. Their work illustrates how social relations form a vital part of capability and points to the need for policy to take this into account (Middlemiss et al., 2019). The community capability perspective helps identify the practical implications for social relations helping to overcome other capability 'deficits' or 'barriers'. For example, a well networked community with high levels of social capital can overcome trust and awareness issues where the SLES offer is introduced by an intermediary who is 'one of us'. Sensitivity to actor and community capabilities also ensures services are designed and presented in a way that makes sense and appeals to particular social groups or market segments.

The capability of the system to create fair outcomes and to replicate

Ecosystems change and evolve naturally. If a local energy system can become established and then go on to create new niches that make social, economic and technical "sense" in the context of the wider system, we could expect the entire system to transform, perhaps rapidly. Part of the definition of making "sense" is that the SLES (and the local energy marketplace that serves it), deliver fair outcomes and that real social and environmental benefit is created. That means that existing disadvantage and inequity in to accessing affordable energy services is recognised, quantified, mapped and targeted with interventions. Interventions either, a) change actor capability so that the energy services or SLES benefits become accessible or b) change the SLES offer itself to meet and work with the communities' capabilities as they stand. For example, in a low-income area with low digital technology skills, households are less likely to have the financial resources or the skills to invest in smart control systems which can extract valuable flexibility from their appliances, Interventions could either attempt to a) increase financial and digital skills capabilities, for example by giving energy advice and ensuring that households are claiming all the social security benefits to which they are entitled or b) install and commission a control system that could be paid for out of revenue from the sale of flexibility. Interventions which change the possible ways of existing and thriving in the SLES ecosystem can operate in any of the four domains described above. Understanding the required actor, community and system capabilities for a SLES to survive and thrive whilst still delivering fair outcomes is a central challenge of Project LEO. A transitioned energy system which can ease existing inequities and not create new ones is both ethically desirable and is more likely to attract political and social support without which the SLES is unlikely to be replicated or scaled.

Conclusion

A radical restructuring of modern energy systems is under way, bringing in many new actors, technologies, connections and practices. This opens up new sources of benefit but also new types of vulnerability and inequity. Taking part in a SLES implies not only having access to energy assets but also the ability to use them gainfully. Therefore, whilst SLES offer many potential gains, at the same time they add a new dimension to energy poverty: lack of access to the technologies and processes needed to participate in, and benefit from, SLES. To explore these new dimensions of energy equity we have drawn on the concept of capability and noted its usefulness in expressing ability to participate in a SLES, individually and collectively and find that a focus on capability may well be the most promising approach to preventing or reducing energy poverty and to achieving energy equity.

Our work also finds that the capability approach applied to individual and organisational actors is usefully supplemented with analysis of the special kinds of capability that emerge at the community level. In addition to the physical assets that are shared at community level, communities can also benefit from sharing knowledge, skills and financial resources. These kinds of community capability are closely linked to the concepts of bridging and bonding social capital. Social capital is itself linked to social advantage (e.g. higher income and education levels) and therefore inequities in accessing SLES benefits will also exist at the community level. The capability concept also fits well with a social-technical approach to energy system analysis and therefore has proven useful in thinking about the dimensions of capability of the energy system as a whole in allowing SLES to become embedded, replicate and ultimately to thrive. Thus, the capability approach is helpful in identifying which aspects of the policy and regulatory framework need to change to facilitate SLES at the system level.

Project LEO recognises that systems enabling energy transition are only successful if they lead to fair outcomes. That means access to the benefits of a smart local energy system is as equitable as possible. In practical terms that means if a householder or a business doesn't have the requisite capabilities to participate in a Smart Local Energy System, a fair approach will be to consider how capability can be increased, whether the offer can be adjusted to match capability or whether benefit can flow indirectly through other channels.

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