Smart and sustainable, fast and slow

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Abstract

The 'smart energy solution' concept is a powerful one, implying rapid, smooth processes and results, with technology in the driving seat. Sustainable communities, by contrast, are works in progress: they require people to develop, maintain and adapt infrastructures, processes and governance over long periods. As the need to stabilise Earth's climate becomes more and more urgent, the appeal of 'quick fixes' grows. But smart solutions are rarely as quick and straightforward as they appear in blueprints. Even in completely new settlements, fast-changing devices are installed alongside slow-to-change infrastructure elements such as buildings, transport networks, pipes and wires. Actors and organisations that are responsible for building, operating and adapting energy systems will learn and change at varying speeds. Regulations take time to develop and often lag behind operational requirements, hence the need to pay close attention to logistics and flexibility when planning and implementing energy systems. If the systems are designed to be 'smart', new types of connectivity add complexity and risk alongside potential control benefits.

The paper outlines two examples of smart energy innovation at different scales: a large-scale demonstration of smart residential storage heating in three contrasting European countries and a project to enable a rural community to gain more value from local solar generation. The first focused on technology and customer experience; the second, on place and community. In each case, the smart technologies took longer than expected to establish, devices and people did surprising things, longstanding rules stood in the way of implementing socio-technical possibilities, and 'middle actors' were able to play an important role in negotiating challenges and making it possible for environmental and social benefits to emerge. Fast- and slow-moving processes were taking place at the same time and on at least three levels: regulatory, system-operational and user-operational.

Introduction

Definitions of sustainability are contested but here it is assumed a sustainable community will last because it is acceptable in ecological, economic and social terms: promoting ecosystem health and not using resources that cannot be renewed; affordable; operating in such a way that most members gain and no-one suffers unduly. Sustainable communities are, by definition, durable.

But communities contain humans who are born, grow, learn, make mistakes, gain or lose abilities and power, and eventually grow old and die. Even durable human communities are dynamic. And that is only part of the story: humans are only one type of living being in complex ecosystems, full of other organisms and non-living elements that change over time at different speeds. Stones, bricks and concrete erode; electrical and radio connections are introduced or fail; forests grow and diversify or are cut down or replaced by monocultures; soil fertility is depleted or enhanced; freshwater becomes more or less fresh.

Transitions therefore will always involve shifting patterns of actors. So when we talk about transitioning to [more] sustainable communities, we are not talking about transition to a fixed state but to new coalitions of materials, people and other living things that can be maintained and developed in ways that are sustainable in the long term. Emergent events are inevitable in such complex systems, with unexpected consequences.

Smart (ICT-enabled) technology is generally seen as disruptive, something that will continue to make radical changes to our lives as it penetrates into new areas and processes. At the same time, though, it shows many signs of 'business as usual'. Smart technologies still rely on established infrastructures and a range of actors for impact; they have to adapt to physical, social and legal conditions and people have to be trained to incorporate the new equipment and processes into their daily lives and work. It is not surprising that many attempts to introduce smart technology into highly complex systems fail, or take longer than anticipated to establish.

Hopes and money are invested in visions that can differ widely in the extent to which they rely on demand-side change and new configurations of supply and storage. However, they typically involve a substantial move towards electrification of transport (and, in Europe, heating); and a much greater role for renewable supply with an attendant move from demand-led to supply-led systems. Smart technology is seen as playing a crucial role in enabling this change, for example

- Locating problems and isolating areas of the grid to prevent them spreading;
- Remote control of some end-uses and storage devices to balance demand with supply in real time;
- Remote consumption, generation and export metering.

Complexity and timing matter greatly in the context of climate change: the longer we continue with dysfunctional energy systems that result in high levels of carbon dioxide and other greenhouse gases, the more pressure is likely to grow for high-risk processes such as geoengineering. On the latest scientific consensus, our global carbon budget will last for fewer than 12 years before we run a more-than-50 % risk of breaching the 1.5 °C warming limit (IPCC, 2018). At the same time, billions of people still aspire to modern energy services and the governments of the world all subscribe to the Sustainable Development Goals. Is it possible to steer a course between over-hasty energy 'solutions' that fail to function and alienate people, and over-cautious processes that fail to meet the urgent need for change?

This paper analyses some relationships between speed, technology adoption processes and outcomes. It briefly discusses energy transition in general terms, then reports on two projects that demonstrate how communities of different sorts and at different scales were able to achieve more flexible demand and facilitate more renewable electricity supply, with assistance from smart technology. It illustrates the range of social, technical and organisational factors involved, and the different timescales on which these can change.

Energy in time: transitions and sustainability

Much of the literature on energy transition discusses shifts from one energy or power source to another. For example, from biomass to coal as cooking fuel, from coal to gas for electricity generation, or from candles to gas to electric lighting. But sources are far from being the whole story. As Sovacool (2016) points out, a transition may include any or all of the following: a change in fuel or power sources, a change in demand patterns, or a switch from an economic system dependent on one set of energy sources and technologies to another. Energy, the ability to do work or make change, is inevitably associated with a huge number of activities, actors and materials; while energy systems show path dependencies that inevitably influence the pace at which they can change. Sovacool concludes that this means that 'most energy transitions … will likely continue to be path – dependent rather than revolutionary, cumulative rather than fully substitutive … Fast transitions have occurred and are capable of occurring, but they only become apparent when one carefully adheres to a particular notion of significance, society, energy resources, and energy services …' (ibid., p. 212). This is important when thinking about the promise and actual growth and form of smart energy systems. Yet smart transitions can display many ordinary characteristics. While attempting to decarbonise with the use of advanced ICT, actors still face the needs to adjust in order to fit with other actors, infrastructures, processes and rules. Smart systems that work for certain actors in a particular context may be unsuitable for scaling up, while comprehensive 'top down' designs will need adapting to local conditions.

We cannot assume that any smart solutions are sustainable until they have been thoroughly tested in real life; by definition, sustainability has to be demonstrated over time. Even when policy is strongly directed at eliminating our use of fossil fuels from energy systems, with ICT as a tool to assist with this, we are still discovering how this works in practice and what will be sustainable.

LOW- AND ZERO-CARBON ELECTRIFICATION: ENTER THE SMART GRID

The shift from centralised fossil fuel and traditional hydro power plants to highly-distributed and renewables-based generation has already been assisted by ICT/smart technology. Strbac et al. (2016), identify four key features for future-proofing an electricity system: flexible generation, interconnections between networks and grids, demand-side response and storage technologies; the second and third of these use ICT extensively. They also recognise that each of the four has associated organisational needs: standards, codes and defined processes. As transitions are both complex and uncertain, with investments, processes and learning moving at different speeds, system planning needs reform: the authors propose a 'portfolio approach' to allow for flexible change. The Future Power Systems Architecture programme in the UK, taking a comparable view, recognises the uncertainties and attends to both processes and functionalities: what will stakeholders need the system to do, and how? For example, the report on Phase 2 of the programme comments that

> The speed of change in the energy sector is such that if we wait for certainty before we act, it is likely that development of the [electricity] system will not be quick enough to respond to changing stakeholder requirements, and system functionality will become inadequate for the needs of society. Despite the uncertainties, it is possible to draw conclusions about likely future requirements of the power system,

> and this can be used to identify **a direction of travel** for innovation and development. This then becomes part of an **iterative pathway** that … will provide flexibility and agility while maintaining safety, sustainability, cost-effectiveness, and security of supply (IET, 2017; my emphases)

Electrification, in this analysis, has to be fast but above all flexible. There is likely to be strong interest in processes that can be established now – including demand response – pending larger-scale developments such as international interconnectors and widespread use of storage tech. Indeed, the effectiveness of the former will influence the need for the latter.

Some sociologically-informed smart grid analyses point out features that will hinder effective working and environmentally sustainable outcomes, such as unrealistic ideas about technology users and their agency (e.g. Skølsvold et al., 2015). From a purely technical standpoint, too, any vision of fully interoperable and fully reliable systems is unlikely to be achieved through reliance on proprietary products and services, or through millions of interconnected devices that are vulnerable to hacking. The utopian strand of thinking about smart cities, communities and buildings (Huber and Mayer, 2015; Strengers, 2013) has to be translated into terms of everyday functions, devices and activities: 'smart' becomes useful through becoming ordinary. But there is little detailed follow-up of smart technology, once installed and in use, compared with the 'prospective' research that shows, from computer models, what *could* be possible, and a growing body of research points to the need to evaluate smart innovations over time in real-life conditions (e.g. Mourik, 2014; Gram-Hanssen and Darby, 2018). Only through this can we start to understand the dynamics and outcomes of communities and cities as they incorporate electricity and ICT, in different ways and at different speeds.

By studying the spread of smart energy in time, it becomes possible to find some common ground between techno- and people-centred approaches. Operational dynamics are important for both: for example, electricity demand flexibility has value because it enables different parts of the system to change at different paces, not just because it supports more efficient use of inflexible generation. It is not hard to recognise that energy systems, smart or not, are complex and unlikely to evolve at a constant or predictable speed.

To illustrate some of these dynamic aspects of attempts to become 'smart and sustainable', two examples are discussed below. Both involve communities, but of different types. The first is a group of three neighbouring villages in southern England, while the second is a more virtual community of electricity customers in three separate European countries, connected by participating in a technology demonstration project.

PLACE-BASED COMMUNITY ENERGY TRANSITION

Geography matters when describing and analysing energy systems (Bridge et al., 2013; Darby, 2017). Each system or subsystem will have characteristic infrastructures and patterns of actors, knowledge and material assets. The term 'community energy' usually refers to 'communities of place' that typically share a low-voltage network. Citizens who live and/or work close together will also belong to social networks that influence demand patterns and, increasingly, decisions on whether to invest in distributed supply and storage. There can be legal and financial benefits from place-based energy initiatives if, for example, community co-operatives are able to raise money to pay for generation assets (Boait et al., 2019). Place-based community energy may or may not promote social cohesion and helpful awareness: much depends on context and on how programmes are planned, debated and carried out (Walker et al., 2010; Burchell et al., 2016). But there can be benefits from building up new bodies of knowledge, practical know-how and social capital that can be put to use in a specific area (Ornetzeder and Rohracher, 2006).

A recent project in three neighbouring villages in southern England deployed smart-enabled technology to promote low-carbon transition along with community welfare, with a strong focus on involving users and developing local capacity. The project title, Community Electricity Generation, Aggregation and Demand Shaping, indicates the technical scope and scale or the work, to test a model that allows for local use of local renewable supply. It involved the occupants of 48 homes, 14 of which hosted solar PV panels (45 kWp in all). Six homes had electric storage heating and water heating (approx. 60 kWh of storage capacity per home), while nine hosted 2 kWh-capacity batteries. (Details are given in Boait et al., 2019.)

Generation, storage and demand were brought together in a business model that included a (virtual) static time-of use tariff that was adjusted each day according to weather forecasts; back-end technology to schedule heating and some other loads at optimum times for the tariff and in line with user preferences; and feedback on usage and on the savings achieved by individuals and the group as a whole – that is, benefits to the local economy. The project budget included funds for a member of the team to spend a day each week on community engagement activities such as organising social events and making home visits. Project personnel were committed to supporting users and willing to spend time explaining and discussing the project with participants, and making prompt 'troubleshooting' visits if necessary. In effect, they were 'middle actors' (Parag and Janda, 2014), equipped with useful knowledge and skills, familiar with the purposes of the project, and in communication with community members.

What of timing? The project lasted 30 months, which proved adequate for testing the business model and demonstrating beneficial effects in terms of avoided electricity exports to the grid, user satisfaction and gains to the local economy. The full 30 months was needed, though, to allow for initial difficulties in setting up devices and making them work effectively. During the year of full demand-response operation, households with PV used 42 % of their own generation[1] but the other householders in the project – and the local economy – benefited from shared use of a further 51 % at a favourable tariff: only a small proportion had to be exported to the grid, for which the PV owners were paid ~€0.06 /kWh.

Since the close of the project in May 2017, the concept is being developed in at least three areas in England and Wales, while the groundwork is being laid for others (Energy Local

1. This is roughly in line with the estimated national norm (McKenna et al., 2018).

website). In social terms, the project lasted long enough to generate plenty of goodwill – as shown in the final party – and some commitment to both demand response and demand reduction. For example, in the final survey of the project, with 17 out of 31 respondents stating that they had load-shifted and/or reduced overall electricity use *and* intended to continue doing so. In terms of perception, this initiative raised awareness of the 'time' dimension to new renewable supply: for example, over a third of respondents to the final survey claimed that their decisions to load-shift were based primarily on 'looking at the weather' to see whether the solar PV would be generating (Boait et al., 2019).

The project was relatively small-scale and straightforward in design. Many participants were already subscribers to local renewable energy co-operatives, so the charitable trust associated with these co-operatives was able to recruit for the project from a community that was broadly familiar with the principle and practice of renewable electricity generation. The participants cannot therefore be seen as representative of the general population, but they were not uniform as a group: they covered a range of socio-demographic characteristics, lived in varied housing types and sizes, and showed varying levels of knowledge.

Most of the technological elements were already tested at the outset; as so often, most technical issues arose not from individual pieces of equipment but from connecting them effectively. This took time, effort and ingenuity. While there were no language barriers to be overcome in this single-country project, everyone learned some new vocabulary and concepts in the course of the trial through talking with others during meetings, social events and everyday conversation. There were a few surprises, such as the relative lack of impact from smart-plug-enabled appliances, a semi-automatic means of load shifting, and the strength of support for further initiatives from the project participants at the end of the trial. The relative simplicity of the project certainly helped to achieve its aims within the time allowed, opening up the wider question: how far, and in what conditions, can this model of smart-enabled community energy be scaled up?

TECHNOLOGY-BASED STORAGE TRANSITION

The second project, RealValue, also had a strong business model component and a social dimension: it was set up to demonstrate the viability of a mix of technologies, activities, processes and regulatory arrangements and, as with the first project, there was a strong interest in scalability. However, it differed from the project described above in being more complex and involving different types of community – industry, commerce, customers, engineers, academics – linked by their interests in a new application for an established technology.

The project was set up primarily to demonstrate new Smart Electric Thermal Storage (SETS) space – and water-heating systems in approximately 800 properties (mostly homes) in Ireland, Germany and Latvia; also, on a much smaller scale, legacy storage heaters retrofitted with gateways to enable smart control or, more accurately, 'smar*ter* control'. Storage heating and some electric water heating were originally set to charge overnight, with customers paying a tariff to reflect the lower cost of night-time generation. The heaters were automatically switched on during the night, leaving customers with some control[2] of how much charging they required the following day (input control) and how rapidly they wanted the devices to discharge heat into the building during the day (output control). The aim of the project was to extend this basic form of day/night load shifting and make it more fit for purpose in electricity systems with high levels of variable renewable supply. Within constraints set by the customers when they programmed their new, well-insulated heaters, it would be possible for a demand aggregator to charge the heaters at any time when supply was plentiful and, potentially, to switch them on and off briefly to offer ancillary services to a network or grid.

Participating customers were recruited to the project by electricity suppliers who offered them *new* heating equipment and (in some locations), the possibility of taking up time-of-use tariffs. The Irish participants also received a monthly discount of €10 on their bill for taking part in the trial. Participants varied from low-income households in social housing (the largest single group) to middle-income and a few upper-income owner-occupiers, with a small number of commercial customers. There were a high proportion (43 %) of retired householders among the domestic customers surveyed and nearly 9 % were unemployed. Many were therefore likely to be at home for much of the time, something that would influence their heater settings and potential for demand response. While there was no formal assessment of fuel poverty, 8 % of survey respondents reported income levels below, or on, the 'at risk of poverty threshold' for their country; home visit observations indicated that this was an underestimate (Darby et al., 2018). The participants cannot be seen as representative of the general population but the intention of the project was to concentrate on customers who already had storage heating and these tend to be clustered in particular areas and demographic groups, such as tenants in apartment blocks, people without access to a gas network, and/ or those in an area where a utility had promoted storage heating as a 'sink' for night-time generation.

Project partner organisations tested not only single items such as heating appliances, smart meters, sensors, gateways, customer controls and aggregator software, but the combinations needed to allow storage heaters and water heaters to charge flexibly at any time of day when supply was abundant, while (as in the first project, above) meeting users' needs for warm buildings and hot water, as expressed through the controls. The aim, as set out in the funding bid, was to demonstrate how small-scale energy storage, optimised across the EU energy system with advanced ICT, could bring benefits to all market participants across a value chain that runs from householders through to system operators; to prove the technical and commercial potential of such storage across representative regions of the EU. It could also be seen in terms of studying the impact of integrating new technology into the daily life of homes and businesses and, at another level, into the technical, regulatory and economic conditions in European power systems.

2. In practice, this was not very satisfactory: customers had to remember to adjust input controls according to the next day's weather forecast each evening if they wanted tight control of charging; insulation on the heaters was often inadequate, so that much of the heat often leaked out by evening and customers had to 'boost', using expensive peak-time electricity; and the controls were not easy to understand.

Community, in this context, can be understood as a community of thermal storage users. In the project context, it was also a community of customers recruited by one of three electricity suppliers, as project participants. They were widely distributed across Europe but clustered in specific places, such as blocks of social housing in Irish cities or suburbs in the distribution area of a German utility. The project therefore offered insights that may be relevant to other user communities, such as owners of electric vehicles or heat pumps.

It is only possible to offer a very brief summary of the project here; more detailed accounts and analyses can be found via the project website (RealValue, 2018), including a report that focuses on the customers and their experiences, and on the process of implementing smart thermal storage through cooperation between diverse actors (Darby et al., 2018). These set out how and where the smart technology proposition was found to be viable; also how implementing smart thermal storage offered valuable lessons and some cautions to industry and policymakers. For example, adoption was complex because of

- the number and diversity of actors (customers, manufacturers, software developers, demand aggregators, electricity retailers, network and grid operators, app developers, consultants and academics).
- rules to be negotiated in different countries, e.g. relating to funding, health and safety, consumer protection, metering and billing legislation, software protocols.
- the need for customer support and the transfer of knowledge and know-how to operate the new heating effectively for comfort and for demand response.
- the complexity of the data operation. For example, in Ireland, the IT supplier reported deploying 700 gateways and 200+ 'behavioural sensors', carrying out 25 software updates, collecting 750 m data points, managing >1,000 security patches and correcting >3 m data records.

Broadly speaking, participating customers were satisfied with their new heaters and with the care taken to address problems, although many of them experienced an upset during software upgrades, when heaters either failed to operate (in one country) or over-charged (in another, with a different aggregation system). Nearly two-thirds of the German customers surveyed at the end of the project stated a preference for traditional overnight charging compared with fully flexible charging: they were not yet ready to commit themselves to a more complex arrangement. However, by the end of the project the participants largely supported the *principle* of demand response as a way of supporting renewable generation, provided it did not affect their comfort and they did not lose out financially.

In policy terms, scalability was an important issue: if the smart, highly distributed electric thermal storage is viable and offers benefits, where and how should it be deployed? It became clear that there were regulatory, social and local dimensions to 'smart' deployment. For example, there had to be infrastructural and regulatory support such as smart metering and the ability to offer time-varying tariffs. Scaling up also meant standardising processes and offering consumer safeguards suited to each country. Flexible demand had to be valuable enough for all the demand response actors in the value chain to gain something from selling that flexibility: there had to be a high penetration of non-dispatchable supply or substantial difficulties in meeting peak demand. Storage heating had to be seen as a viable heating option for buildings in a given area, bearing in mind that it is far less efficient than heat pumps and large amounts of storage heating could lead to unmanageable strains on local networks. Finally, there had to be customer support, on a greater scale than had been predicted and using different modes of communication, from home visits to automatic fault detection and follow-up. Installers and 'local champions' emerged as key sources of care. Partners' engagement efforts involved a lot of 'middle actor' activity: listening, informing, advising and developing customer packages to make smart thermal storage an attractive proposition. For example, some customers had not felt confident with their new digital heating controls and settled for something 'just good enough', in order to avoid altering the settings from day to day. On-the-spot guidance from an installer, housing manager or helpful neighbour was able to improve such a situation.

Where timing is concerned, three years was barely long enough to establish the viability of fully flexible small-scale electric thermal storage. While elements of the system were tested throughout, it proved very challenging to connect them all, and only during the third heating season did two-thirds of the customer loads become available for flexible charging. (The entire load could not be available due to issues such as lack of smart metering, or customers switching their devices or gateways off.)

What is industry learning from such technology trials? Following the end of the RealValue project in spring 2018, one of the commercial partners went on to develop a customer demand response offer with flexible electric vehicle charging and rooftop solar PV. While this does not involve storage heaters, it uses experience gained during the project (Beegy, 2018). The German utility project partner was proceeding with smart retrofits of legacy storage heaters to enable fully flexible operation: it found a business case for that, though not for replacement with new (more efficient) smart heaters. At the time of writing a suite of new commercial offers is available in the UK that includes retrofitting storage heaters, along with smart vehicle charging and home battery storage (CleanTechnica, 2018). This last development has no direct link to the demonstration project as far as I know. Yet since the project was conceived, the supply industry has clearly become more willing to move into demand response, and customers are now able to consider taking up demand response offers.

In terms of speed and sustainability, the project was typical of many: original plans had to be modified in the course of a slower-than-expected rollout, while the process of implementing those plans showed, very effectively, how smart technology innovation relies on a range of actors, rules and procedures that change at different speeds.

Tables 1 and 2 summarise some of what was learned in the course of these two projects.

Discussion and conclusion

Visions or imaginaries of a low-carbon, sustainable future occupy a broad spectrum. It runs from high-tech, highly-connected, high speed societies running on abundant renewable

Table 1. Regulatory environments for the two examples of smart-enabled energy development.

	Place-based community (English villages)	Technology-based communities (in Ireland, Germany, Latvia)
Policy background	UK Government produced Community Energy Strategy in 2014, a framework to encourage energy saving and generation initiated by communities and local government. It included funding for pilot projects, including this one.	EC climate goals and backing for smart grid innovation. National programmes including growing penetration of wind power in Ireland and of wind and solar in Germany. The German Energiewende; Latvian moves towards more energy independence.
Strategic aim	Match local supply and demand using a community-based business model with social engagement and demand response technology including thermal and battery storage	Replace/upgrade electric storage heating and water heating with ICT connectivity to provide flexible demand on a large scale across Europe.
General conclusions	Valuable technical, economic, and social outcomes can be achieved by localising electricity generation and consumption within a community-of-place-based framework. Complex tariffs need not be over-confusing if supported by tech and reasonably intuitive (e.g. users can easily see when sun is shining). Customer experiences broadly positive, reflecting effective support in understanding and engaging with new technology and tariffs.	Market access for smart thermal storage, market rules, supplier interest and grid regulation are all issues for EU countries and can vary substantially from Member State to MS. Implementation of new Grid Codes is still under way, at differing speeds. Customer experiences broadly positive: these relate to comfort, cost, control, connectivity and care.
Further needs at national/ regulatory level identified	Regulation of tariffs to allow users to benefit from user of DR technology; development of potential to contribute to balancing services for National Grid;	Value of flexibility may often be at regional/ distribution level, e.g. avoiding or resolving constraints. But there are no regional and local price signals in many EU countries and aggregated loads are not yet accepted in most power and balancing markets. Smart meter rollout patchy.

Sources: Boait et al., 2017, 2019; Darby et al., 2018; RealValue, 2018.

Table 2. Operational considerations for the two examples of smart-enabled energy development.

	Place-based community (English villages)	Technology-based communities (in Ireland, Germany, Latvia)
Aim	To combine demand with a realistic time-of–day tariff provided by an electricity retailer and with community engagement, to influence aggregate demand in order (a) to use locally-generated electricity as efficiently as possible, benefiting local economy, (b) to minimise demand during a 17.00–21.00 peak tariff period.	To combine physical demonstrations with modelling to demonstrate how local small-scale energy storage, optimised across the EU with advanced ICT, could bring benefits to all market participants.
Participants	Householders in 48 homes; range of incomes, education levels and housing. They lived in three villages close to a cooperatively owned wind farm and solar farm.	~800 premises, mostly homes. Sample included many social housing tenants as well as homeowners and a small number of commercial sites.
Organisational actors	Project leader, 3 commercial and manufacturing partners, 2 academic partners	7 manufacturing and commercial partners, 5 academic partners, 3+ commercial subcontractors
'Middle actors'	Project personnel, including installers, equipment manufacturers, community liaison manager and researchers.	Utility support staff, project coordinators, equipment installers, housing managers, researchers.
Non-dispatchable renewable generation	14 homes had solar PV, 45 kWp in all.	Input to national grids from varying mixes of wind and solar.
Demand-side devices	Smart-enabled electric storage heaters and water heaters in 6 homes; 2 kWh batteries in 9 homes; smart metering and control units plus appliance smart plugs for all participants; smartphones/tablets for user inputs and feedback.	~800 properties with smart-enabled electric storage heaters and (for some) water heaters. Gateways, sensors, controls; online devices for control and feedback.

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Table 2. Operational considerations … (continuation).

	Place-based community (English villages)	Technology-based communities (in Ireland, Germany, Latvia)
Connectivity	Project database server, Internet to supply weather forecast data, temperature sensors. Heating control hubs for those with storage heaters.	Project database servers for suppliers, complex 'aggregator backend' with optimisation engine and interfaces with customers, grid and markets; Internet to supply weather forecasts and 'dashboard'-type feedback; temperature sensors; modems, gateways; heating controls on heaters and via mobile apps.
Business model	Homes without PV able to consume electricity from neighbours with PV, at a favourable (virtual) ToD tariff, with financial savings for both. Some had thermal/battery storage that was automatically controlled (with user override) to respond to availability of low-cost electricity due to PV generation or static time-of-day (ToD) tariff	Use by aggregators of distributed thermal storage assets (owned by building owners/landlords) to provide network/grid flexibility services, with value shared between aggregators and customers.
Data flows	Web-based display of tariff and consumption for participants. Data from home hubs and smart plugs showing user needs for heating etc., for use in scheduling loads; feedback to users on financial savings.	'Optimisation engine' receives data from wholesale markets, customers (controllable load size, service requirements) and weather forecasts; communicates with network and grid operators; also heating/charging schedules to each customer.
Tariffs	Combination of a [deemed] static ToD tariff with a dynamic adjustment reflecting predicted availability of local PV generation.	Actual time-of-use tariffs unavailable, beyond traditional day/night tariffs; deemed time-of-use tariffs were used.
Outcome for participants – energy service	Good.	Broadly good: most participants appreciated new, more efficient heaters and reported greater comfort. Some difficulties in adjusting to digital controls, especially among older customers. A software upgrade caused problems at one point.
Outcome for participants – social	Strengthened community, especially via events arranged for information and celebration; and by the support offered by liaison officer (one day per week throughout project) and other project staff.	Person-to-person care from project personnel, housing managers and neighbours was seen as part of a good customer experience. Participants broadly positive about the project and its aims.
Outcome for participants – financial	All participants gained (according to simulated tariffs and actual operation.) PV owners gained approx.€55 /year from their generation. They were able to use 42 % of the electricity they generated and a further 51 % was matched with local consumption; more money stayed in local economy.	Data incomplete: German supplier reported that participants who operated their equipment in the way intended had reduced bills. For the rest, various *perceived* outcomes were reported: gains, losses and 'no change'.
Implications	Sustainability/durability of transition to renewables can be strengthened through a community-oriented approach that supports users in making technological change and improves RoI by matching local consumption with generation. Users need to maintain override control of their appliances. Need sustained, accessible user engagement/support to ensure participants are confident and well served.	The best outcomes can come from a combination of reasonable expectations, reliable technology, skilled middle actors and well-planned, diverse forms of engagement with technology and people.

Sources: Boait et al., 2017, 2019; Darby et al., 2018.

energy, through more efficient versions of current societies, to sufficiency and sobriety and, at the far end of the spectrum, 'slow living', with its attention to ecosystem rhythms and quality of life. It is easy to argue that time is in short supply - we are already in a period of climate crisis and it will deepen for the foreseeable future – and that we have to act fast and effectively in order to lessen the scale and impacts of climate change and ecosystem depletion. For that reason, promises of speedy, easy-to-implement technical fixes are appealing.

But we also know, from theory and increasingly from experience, that climate change is a 'wicked', multidimensional problem and that sustainable systems are long-term works in progress: they require people to develop, maintain and adapt infrastructures, processes and governance. From that point of view, there are strong arguments for respecting and working with complexity rather than rushing to simplified solutions (Rayner, 2012; Stirling, 2016). (Apparently) quick routes to decarbonisation may be false friends, generating more difficulties than they solve. (Apparently) well-functioning systems may fail, and over-reliance on them can produce crisis when there are no effective, scalable 'Plan Bs' (Kemp, 2017).

This brief account of two attempts to develop more sustainable energy systems, at different scales, illustrates the significance of

- the *complexity* inherent even in relatively straightforward 'smart' projects. They rely on sophisticated connectivity, often between proprietary products without adequate interoperability, and the products, systems and processes typically take time to set up, learn from and maintain. Smart initiatives also rely on regulatory support and on competent, experienced actors.
- *relationality* and the role of intermediaries in negotiating relationships: people with people, rules with operational requirements, people with technology, and technologies with other technologies.
- *Scalability*: how well can a solution for one place and one set of actors work in another place, with different actors?
- *durability and resilience*: what is the adaptive capacity of a system or subsystem? How well is it equipped to face shocks and incremental changes such as software upgrades or changes of personnel?

Whether the focus is on technology or on place and community, these case studies strongly suggest that it is reasonable to expect the unexpected, from both technologies and people. They also illustrate the essential roles played by 'middle actors' in negotiating change and making it possible for environmental and social benefits to emerge. A typical schematic diagram of a smart energy system shows a number of artefacts linked by wires or wireless signals. A more realistic picture would include the people who will inevitably be involved in designing, installing, connecting, explaining, adapting and troubleshooting such a system.

These considerations help us in understanding a little more about fast- and slow-moving processes in energy systems. At risk of overstating the obvious, people and processes move at very different speeds and at different levels. Some things can happen near-instantly, e.g. a personal decision to buy an electric vehicle (EV). Others, closely related, can take far longer – e.g. establishing a charging infrastructure for EVs; rethinking mobility. We can identify at least three levels:

- Policy and regulatory. Policy develops at speeds that are partly determined by shifting political alignments, partly by crises and operational requirements. For example, the massive European 'Winter Package' of 2016, *Clean Energy for All*, attempts to change the policy landscape for the EU. Years in the making, it includes proposals on market design and regulation, efficiency, renewables, governance and building performance, all of which need to be consistent with each other. Yet they do not all have a timetable for implementation and, even if they did, it would need revising. Member States lay the groundwork for low-carbon infrastructure at their own pace, even when they are attempting to comply with an agreed overall agenda (e.g. Darby et al., 2013).
- System operation. This is an immensely relational business, needing effective communication between technologies, technologies and people, people and people. People (and, now, machines) learn at different rates and learning is influenced by whether good data is available, along with people able to make sense of it. Trust in data quality and trust between actors are important (e.g. Kalkbrenner and Roosen, 2016; Higginson et al., 2018), and each takes time to build.
- User operation. The examples of 'smart, sustainable' energy offered here both relied on householders going about their daily lives and incorporating active demand into those lives. The larger project was based on heating, a service that is fundamental for comfort and that people operate in relation to weather, built environment, heating systems, cultural norms for clothing and personal perceptions of comfort – all variable in time and subject to change in different ways. The smaller one relied on a combination of technologies, community spirit and personal communications so that the participants could learn new ways of going about the business of using distributed generation, storage and demand. Both projects illustrated how change is planned, tested, negotiated and developed over extended periods, in line with evidence from several other community- and household-level energy initiatives (e.g. Burchell et al., 2016; Fawcett, 2014).

Geography also influences timing. In the second project, implemented in three diverse EU member states, allowance had to be made for all the national differences *and* specific locations: the technology could not be deployed in the same way in each situation. While network operators tend to have good information on where generators are installed, they have much less on where different types of demand are located. As EVs, heat pumps and new forms of storage proliferate, this becomes a serious concern with implications for timing.

All these considerations help to explain why making a system of smart demand management viable is a lot more complex than simply introducing new means of communication and control (ICT) and deploying the magic word 'smart'. New elements have to be incorporated into infrastructures with inbuilt inertia (Unruh, 2007); new relationships have to be negotiated at various levels – among and between users, at system level and at policy/regulatory level.

So smartening, for all its promise of novelty, cleverness and friction-free speed, is in many ways an ordinary, complex and relational process with familiar features to be addressed and lessons to be learned. And sustainability, so durable and solid sounding, is a dynamic state. Smart is not necessarily fast; sustainable is not always slow. Solutions may be integrated on paper but require great effort to integrate on the ground. When thinking about smart and sustainable communities, we need to be realistic, and probably humbler, about what can be achieved in the short and long term. The first half of the old saying – that we tend to overestimate what is achievable in the short term – seems to hold true when we look at the short history of smart technology in energy systems. The second half – that we underestimate what is possible in the long term – may well also be true. For now, it seems time to attend more closely to the relational and human aspects of smart initiatives.

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