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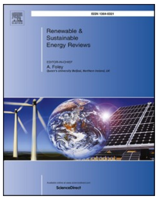

The centre cannot (always) hold: Examining pathways towards energy system de-centralisation

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A B S T R A C T

'Energy decentralisation' means many things to many people. Among the confusion of definitions and practices that may be characterised as decentralisation, three broad causal narratives are commonly (implicitly or explicitly) invoked. These narratives imply that the process of decentralisation: i) will result in appropriate changes to rules and institutions, ii) will be more democratic and iii) is directly and causally linked to energy system decarbonisation. The principal aim of this paper is to critically examine these narratives. By conceptualising energy decentralisation as a distinct class of socio-technical transition pathway, we present a comparative analysis of energy decentralisation in Cornwall, South West UK, the French island of Ushant and the National Electricity Market in Australia. We show that, while energy decentralisation is often strongly correlated with institutional change, increasing citizen agency in the energy system, and enhanced environmental performance, these trends cannot be assumed as given. Indeed, some decentralisation pathways may entrench incumbent actors' interests or block rapid decarbonisation. In particular, we show how institutional context is a key determinant of the link between energy decentralisation and normative goals such as democratisation and decarbonisation. While institutional theory suggests that changes in rules and institutions are often incremental and path-dependent, the dense legal and regulatory arrangements that develop around the electricity sector seem particularly resistant to adaptive change. Consequently, policymakers seeking to pursue normative goals such as democratisation or decarbonisation through energy decentralisation need to look beyond technology towards the rules, norms and laws that constitute the energy governance system.

1. Introduction

Energy decentralisation is nothing if not *de rigueur,* with the term used liberally across academic, policy and grey literature related to the energy system. The number of peer-reviewed energy publications with variants of decentralisation, decentralised or distributed as a keyword has grown significantly in the last few decades, with 1627 such articles published in 2018 alone.[1] Despite wild variation in the use of the term (*what* is being decentralised, by *whom* and the implications of such a definition), implicit in much of the grey literature and some of the scholarly literature is a strong, causal association between energy decentralisation and progress towards sustainable, equitable energy systems [1]. This normative framing of the 'rightness' of decentralisation often rests on the reduced environmental impact of smaller-scale, more geographically distributed, and (usually) renewable energy generation technologies, an associated shift to distributed ownership and decision making, and greater autonomy of individuals in the energy system. As such, the concept of energy decentralisation often finds alignment with concepts of energy democracy and energy justice [2] [2] as well as decarbonisation.

Here we make two points. The first is that 'energy decentralisation'

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[1] Search performed in Scopus, using query:. KEY (decentralisation OR decentralisation OR decentralised OR decentralised OR distributed) AND DOCTYPE (ar OR re) AND PUBYEAR < 2019 AND (LIMIT-TO (SUBJAREA, "ENER")) AND (LIMIT-TO (PUBYEAR, 2018)).

[2] This terms 'energy democracy' and 'democratisation will be used for the purpose of this paper. Acknowledging that this is a contested term, we take the definition of energy democracy developed by Szulecki [2], conceptualising energy democracy as: 'an analytical and decision-making tool, defined along three dimensions: popular sovereignty, participatory governance and civic ownership, and operationalized with relevant indicators'.

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List of abbreviations

AEMO	Australian Energy Market Operator
AIP	Association Iles du Ponant
DER	Distributed Energy Resources
DNOl	Distribution Network Operator
DSR	Demand-Side Response
EDF	Electricité de France
ERDF	European Regional Development Fund
FiT	Feed-in-Tariff
GHG	Greenhouse Gas
LEM	Local Energy Market
LIFO	Last In, First Out
MLP	Multi-Level Perspective
NEM	National Energy Market
P2P	Peer-to-Peer (trading)
PV	Photovoltaic
RTE	Réseau de Transport d'Électricité
SDEF	Syndicat Départemental d'Energie et d'Equipement du Finistère
SRES	Small-scale Renewable Energy Scheme
STS	Science and Technology Studies

can have multiple interpretations, depending on *what* is decentralising – energy hardware, ownership, knowledge, socio-political power, decision-making authority, economic market share and so on [3]. Secondly, we posit that not all decentralisation pathways are created equal, and different decentralisation pathways can have quite different social and technological implications for the future energy system [4]. The starting point for this contribution is to observe that a single definition of energy decentralisation that can encompass the full diversity of practices bearing its name is likely to be so broad as to lose analytical precision. It is also unlikely that all of normative goals associated with energy decentralisation can be fully realised in all circumstances.

Altogether, we argue that decentralisation is often symbolic, as much a narrative shorthand for the direction in which the energy system is (or should) be heading and the values that it ought to embody, as it is a descriptive or analytical device. Consequently energy decentralisation is something of a 'floating signifier' [5], an open category available for population by various actors and interests. Energy decentralisation, we suggest, may be considered an 'energy fable' among other energy "*terms, ideas and stories …*" whose "*… conceptual foundations that have become invisible, worn smooth through use and submerged within familiar discourses*" [6]. That is not to suggest that the associations between energy decentralisation and normative goals are not valid. Indeed, a large body of energy research both theoretically and empirically supports many of these associations. However, we do argue that the conceptual malleability of the term and the wide range of practices that fall under the decentralisation umbrella invite further enquiry in order to develop a more detailed representation of what decentralisation is, and what it means.

To this end, we develop three international case studies of purported energy decentralisation to offer a glimpse of how energy decentralisation is being enacted or, rather, what processes are being enacted in the name of decentralisation. Through these cases we are able to illustrate that how decentralisation is interpreted and enacted can have implications for sustainable energy.

The remainder of this contribution proceeds as follow: section 2 reviews existing literature addressing the topic of energy decentralisation; section 3 develops an analytical approach to energy decentralisation and puts forward the research question that guides the empirical analysis for three cases of decentralisation, presented in section 4. Section 5 reflects on the findings in light of contemporary theoretical discussions. Section 6 concludes and proposes avenues for further research.

2. Defining decentralisation

While the importance of decentralisation for energy decarbonisation is becoming more widely recognised, there remains no commonly accepted definition of the term with definitions shifting in relation to the context [7,8]. Given the complexity of the phenomenon, definitions often reflect the particular facet(s) of decentralisation analysed in different studies; for example renewable generation technologies, ownership, or community energy [8–10]. Across different foci, decentralisation is commonly presented as a counterpoint to 'centralised' energy, the differentiation being that decentralised energy production occurs closer to points of consumption. However, the lack of a single agreed definition gives rise to several ambiguities. Firstly, both academic and grey literature use the terms 'decentralised' and 'distributed' interchangeably [11,12]. Secondly, the term decentralisation is used interchangeably to refer to both processes and normative end goals, particularly when used in conjunction with discussions regarding energy democracy or community energy [13,14]. Thirdly, due to a higher volume of activity in this area, the term energy decentralisation is often applied primarily to electricity decentralisation, despite that over half of global energy consumption is actually for heat [15]. While around 43% of heat use in buildings globally is classed as renewable, this is primarily linked to the use of biomass for cooking and space heating in developing and emerging economies [15]. The removal of fossil fuels from heating, in order to meet the Paris agreement goals, requires the rapid deployment of more distributed heating technologies such as heat pumps and solar thermal (dependent on geography [16]).

Within the electricity sector, decentralisation literature to date has primarily focussed on electricity generation [17–19]. Given the increasing importance of technologies associated with flexibility and balancing services, (e.g. Demand-Side Response (DSR), frequency response, storage, vehicle-to-grid, electrification of heat) that are key parts of a system integrating decentralised generation [20,21], there is an opportunity to expand the focus of future studies. Exploration of the above may also present opportunities to explore new forms of decentralisation across different energy vectors and sector coupling.

It is well established that the diffusion of decentralised energy technologies (e.g. small-scale wind, solar Photovoltaic (PV)) also cannot be separated from social, institutional, economic and cultural drivers and impacts. This paper therefore conceptualises energy decentralisation as a socio-technical transition [22,23].

Despite differing methods and foci, some common themes are identified by existing studies of energy decentralisation. Firstly, energy decentralisation takes different forms depending on the geographic, socio-economic and temporal context in which it emerges [24–26]. Secondly, energy system centralisation and decentralisation and are not mutually exclusive or binary opposites; it is quite possible, or even likely that energy systems will combine elements of both [27]. We also identify a tendency towards certain fable-like [6] narratives, in which physical decentralisation is assumed or expected to lead naturally to certain social or environmental goals.

For example, a link is sometimes assumed between the technological shifts inherent in energy system decentralisation and similar shifts in norms, rules and institutions; albeit with institutional change tending to take place through gradual processes [28–30]. However, in addition to *habituation* as individual behaviour changes to accommodate changes in a technological context [31], institutional change is contextually shaped as a product of complex power dynamics and system characteristics [3, 32–36]. We therefore question the degree to which institutional change is influenced by technological change, over and above other contextual factors.

Similarly, energy system decentralisation is often strongly implied to link with democratic processes and outcomes, although these assumptions are not universal [for example 12,29,30. These analyses provide useful conceptual tools for inquiry into the depth and meaning of democratisation in the context of energy decentralisation. However, to date, this approach has been applied to a limited number of test cases. We contribute to a developing area of literature through critical analysis of democratisation across three international case studies. Our analysis contends that, while decentralisation and democratisation can work together, it is not possible to assume any inherent relationship.

Finally, decentralised technologies and decarbonisation targets are often assumed to be strongly linked. While decentralised energy generation *can* facilitate system decarbonisation, for example through increased deployment of Distributed Energy Resources (DER) and flexibility [21], decentralisation pathways encompass a wider web of social and economic relations intertwined with technological change. A less centralised system is not, therefore, *necessarily* a lower-carbon system. Our analysis examines actor engagement with decarbonisation as an explicit driver of energy decentralisation, noting substantial variability across and within case studies.

3. Approach to analysis

As outlined above, the observable phenomenon of energy decentralisation represents the interaction of numerous processes of change, both social and technical. A great variety of approaches can be taken to the analysis of such socio-technical change. Numerous and diverse conceptual frameworks and heuristics have been created or adapted to order data, structure analysis and offer researchers the benefit of others' insights when planning or conducting empirical research [37]. Latterly, research in this area has expanded its focus to include important areas of politics, discourse and institutional change, into which we offer this contribution [38–41]. We argue that processes of energy system decentralisation are best conceptualised as a distinct class of socio-technical transition [22,23,42]. We take the socio-technical transition – or the bundle of processes it represents - to be our primary unit of analysis. Therefore, we address the comparative analysis of decentralisation pathways through the lens of the socio-technical transitions literature. Specifically we apply the 'pathway' typology put forward by Geels & Schot [23], subsequently somewhat reformulated and broadened to give greater consideration to issues of actor agency by Geels et al. [42].

Geels et al. [42] draw on earlier work[3] to derive four 'ideal-type' pathways along which a socio-technical transition may proceed.[4] The four pathways are characterised by differentiation in three broad analytical categories: i) **actors,** for example, the struggle between new entrants and incumbent firms, but also the activity of other social groups or citizens; ii) the existing and emerging **technologies** that constitute the system; and iii) **rules and institutions**, with a fairly narrow focus on the formal rather than cultural-cognitive institutions and a differentiation between incremental or disruptive institutional change. The four pathways proposed are:

- **Substitution** in which incumbent actors are either overthrown by new firms, displaced by organised groups such as communities or social movements, or are replaced by outside firms. Substitution often involves substitution of existing technology with radical or innovative alternatives. Institutional change can be either incremental, as new firms and/or technologies conform to existing rules, or transformative with the creation of new rules and institutions to accommodate the new actors and technologies.
- **Transformation** in which incumbent firms shape change by adopting new practices and patterns, either incrementally or profoundly. In the transformation pathway, existing technologies may be incrementally improved, complemented by additive innovation or even partially or fully replaced. Institutional change can be incremental or substantial.
- **Reconfiguration** in which incumbents and new entrants form alliances leading to initially modest or additive technical innovation. This triggers a process which, over time, leads to larger and more wide-spread innovation. Depending on the type of technical innovation, the consequences can be incremental or substantial institutional change.
- **De-alignment and re-alignment** in which incumbents fail to adapt to changing contextual conditions, leading to collapse or withdrawal, opening up space for new entrants. In this pathway, new technologies enter the void left behind and compete for dominance. Institutions are consequently disrupted and replaced.

One notable characteristic of the pathways above is that in all but one of the four, changes in institutions and rules may be *either* incremental or substantial. Here Geels et al. [42]turn to the political science literature on institutional change to offer a more fine-grained differentiation of the nature and rate of change, in particular they cite the work of Kathleen Thelen [29]. As outlined above, energy decentralisation is likely to be characterised by institutional change. Therefore differentiation between, and comparison of, decentralisation processes can be expected to require a clear view on institutional change.

Among the numerous insights emerging from the diverse literature addressing institutional change is that, rather than the somewhat rare event of direct replacement of one institutional form with another following disruption by an external event, institutions more often change through the reconfiguration or repurposing of existing structures through incremental processes such as 'bricolage' or 'translation' [43,44]. As noted by Geels et al. [42], for Thelen [29], rules and institutions can be subject to gradual, path dependent change in which new institutional elements are added over the top of the original configuration with little fundamental change in purpose or mission: a process known as 'layering'. Alternatively, changing local context may produce an adaptive but not strategic response of modest, *ad hoc* alteration known as institutional 'drift'. Other modes of incremental change described by Thelen [see 32include 'conversion', the 'redeployment or reinterpretation of existing elements of an institution for new purposes' via reorientation of their objectives [28,30] and 'displacement' whereby 'new models emerge and diffuse' to replace pre-existing institutions [45].

Drawing on the approach set out in this section, the primary research questions addressed in the remainder of this paper are "what types of transition pathways are represented by different examples of energy decentralisation?", "what are the associated institutional changes and limitations?", and "what can this tell us about decentralisation more generally?".

4. Three enactments of decentralisation

Rather than attempting to represent the full variety of decentralisation pathways, our intention is to examine diversity within a geographically, technically, commercially and institutionally varied, but otherwise comparable, set of case-studies [46]. Firstly, all case studies are taken from countries with high national GDP and per-capita income [47] with established energy systems. Secondly, the national governance models of all case study countries can be broadly identified as liberal-democratic, and ensure at least some opportunity for public participation in energy policy-making at various levels of governance. Finally, all case study countries are signatories of the Paris Agreement on climate change [48] and have developed national carbon-reduction plans or targets [49–51], albeit with different levels of change required to meet those targets. The cases are:

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[3] Itself based on interpretations of insights from Science and Technology Studies (STS), evolutionary economics, the neo-institutional tradition of organisation studies, and social field theory.

[4] These pathways are designed to conceptualise socio-technical transitions in a broad sense, rather than those only within the energy system.

- A consumer trial of local energy trading in Cornwall, UK;
- The boom in domestic scale solar PV and electricity storage uptake in Australia; and
- The planned replacement of a single diesel-fuelled power station with distributed renewable electricity generation and flexible operation in Ushant, France.

The three case studies are based primarily on analysis of documents retrieved from the websites of governments and other stakeholders, research articles, media reports and other publically available material. In addition, observational field work was carried out in the Australian States of Victoria, New South Wales and South Australia between February and March 2018, on the island of Ushant in November 2017, and in Cornwall, UK between June 2017 and May 2019. Where possible, citation is made of the original source of information. Collected data were coded and analysed using the themes developed in the preceding section.

4.1. Cornwall local energy market project

The Cornwall Local Energy Market (LEM) project is a three-year trial from 2017 to 2020 jointly funded through the European Regional Development Fund (ERDF) and the vertically integrated energy producer and retailer, Centrica.

Cornwall is outperforming most local authorities in England and Wales in its renewable energy generation, currently ranking 4th out of 56 county areas [52]. Cornwall has a total renewable capacity of around 764 MW, of which 72% comes from solar (where the authority is ranked 2/56) and 17% comes from onshore wind [52]. The local government (Cornwall Council) has set ambitious targets for 2030 which include meeting 100% of Cornwall's electricity demand from renewable and low carbon sources; increasing the proportion of Cornwall's generation that is owned locally to 50% and increasing the proportion of Cornwall's energy 'spend' retained within the local economy to 30% [53].

However, increasing penetration of renewable energy generation is stressing the distribution network, constraining further growth [54]. This is particularly affected by the Distribution Network Operator's (DNO)[5] principle of Last In, First Out (LIFO) [55]; determining that generation assets last to connect to the distribution network will be curtailed first during times of system stress.

In order to overcome the lack of network capacity, Centrica has developed the Cornwall LEM as a local experiment in intelligent management of demand, generation and storage in a constrained part of the distribution network. The core of the trial is an online platform through which the DNO can request, and the local energy market can provide, flexible demand, generation and storage as required to alleviate system stress. In addition, the platform enables the trading of energy and flexibility into established national markets such as ancillary services, balancing and wholesale markets.

The LEM trial however, is revealing the extent to which existing rules and institutions in the UK inhibit greater local trading of power and flexibility [56]. UK markets and network operation have historically been designed to reflect the 'conventional' centralised configuration of the system, rather than supporting smaller scale, more active local participation. Despite some recent changes to ease access to ancillary services and the balancing market for smaller generators, this remains the case. For example, electricity market rules such as the length of the trading period (currently 30-min blocks) and minimum load size (currently 1 MWh) are not conducive to small scale or domestic-level participation, often using variable generation [56].

The LEM trial also aims to develop 'peer-to-peer' (P2P) trading of energy between Cornish residents and businesses. The P2P element of the trial differs to the demand response offering in that rather than network operators requesting local resources to meet individual grid requirements; P2P aims to balance local supply and demand in real-time through the trading of electricity within a peer group.

The concept of P2P energy trading first emerged in the US, where it is more commonly known as 'transactive energy'; but has now gained traction in Europe under various titles such as 'community self-consumption' in France and 'tenant self-consumption' in Germany [57].

However, since privatisation in the late 1980s, electricity supply companies in the UK have acted as the core intermediary between customers and the energy system, in what is known as the 'supplier hub' model. The current market arrangements have evolved and developed around this principle and the supplier's role is now entrenched in legal frameworks, licensing arrangements, and industry codes, regulations and rules [58,59]. For instance, current legal arrangements mean that customers can contract with only one licensed supplier at any one time, effectively blocking electricity trading between peers as multiple, non-licensed supplier/generators. The existing rules therefore make the P2P proposition between generators and customers impossible to enact *independently*, since all transactions must be made through a third-party licensed supplier such as Centrica (who is also responsible for billing and settlement as well as supply). However, a 'true' P2P market could enable independent trading of local energy between participants. If technologies currently being tested in the LEM trial are considered to hold the potential for broader roll-out, these barriers raise questions both regarding the nature of future institutional change as well as the role and business model of actors such as Centrica and WPD.

4.2. Booming distributed renewable electricity generation in Australia

There are currently 1.8 million domestic solar (PV) installations in Australia, with the largest proportion of these (32% of households) in the states of South Australia and Queensland [60]. An average of the total of all of the Australian states in 2015, showed that just over 15% of Australian households had PV installed; double that of Belgium which had the next highest levels. The percentage of Australian households with PV installed rose even further to 23% by May 2017 [61].

The unexpectedly rapid installation rates of solar PV and domestic storage in Australia can be explained by a combination of four main economic and institutional factors: (i) rising electricity prices between 2010 and 2012 [62–64]; (ii) a parallel reduction in the cost of DER technologies [60,65]; (iii) generous government subsidies under Greenhouse Gas (GHG) reduction schemes for installing and generating DER [66]; and (iv) in 2016 a major storm which caused technical issues and initiated a large scale system blackout [67]. Different Australian states have Feed-in-Tariff (FiT) schemes, which have been reduced over time. In addition, FiT solar is supported by a federal government scheme (the Small-scale Renewable Energy Scheme (SRES)) which will run until 2030 (Table 1) [49].

The high rate of uptake also contributed to falling installation costs as competition between solar installers allowed for efficiencies in installation techniques and Australia now has the lowest PV installation costs in the world [69]. High uptake has also meant that companies such as Tesla, Enphase and Sonnen are competing for the Australian storage market [70]. In response to the commercial opportunity presented by this growing Australian market, in late 2016 Tesla announced that they would be introducing their new Powerwall 2.0 home electricity storage product in Australia at the same price as the first iteration of the product [71]. This effectively halved the cost to the consumer of domestic electricity storage, given that the Powerwall 2.0 has twice the storage capacity of its predecessor.

In some Australian states, installing PV plus domestic storage rapidly

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[5] Western Power Distribution (WPD) is the DNO for Cornwall and a LEM project partner.

Table 1
FiT rates for NEM states (2017). (*The mandatory minimum is the minimum Feed-in-Tariff rate that the retailer can provide). Data sourced from Ref. [68].

STATE	Scheme	Rate c/kWh	Max size
Queensland	South-eastern QLD: no minimum Rural QLD: mandatory minimum	Based on retailer competition 6–8	5 kW
New South Wales	Recommended benchmark range for retailers	11.6–14.6	Depends on retailer
Australian Capital Territory	No minimum	Depends on retailer: currently 6-8	n/a
Victoria	Mandatory minimum*	11.3	<100 kW
South Australia	No minimum	Depends on retailer: currently 6-12	First 45 kWh per day
Tasmania	Set rate	7	10 kW single phase 30 kW three phase

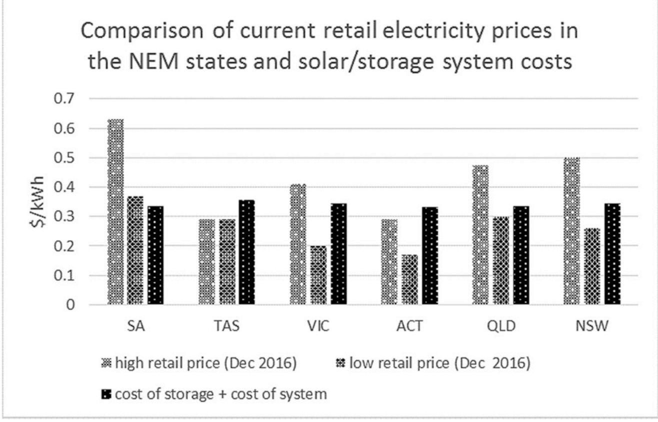

Fig. 1. Comparison of retail electricity prices in the National Energy Market (NEM) states (SA, TAS, VIC, ACT, QLD, NSW) and solar PV/Storage system costs in 2016.

became competitive with grid supplied electricity (Fig. 1).[6] The uptake in DER has also allowed for new entrants to the electricity space with IT platforms [72] and DER management solutions, such as Virtual Power Plants, beginning trials [73].

The amount of solar now on the grid has led to problems for the networks. Firstly, there are constraints on the distribution grid which was not designed for two-way flows of energy. Secondly. PV systems increase the voltage on the 11 kV line, which can lead to transformer malfunctions if the voltage regulation is incorrect. Finally, a high penetration of PV can also reduce the frequency of the network; something which could cause a black-out of the entire system. Without adjustment, there would be potential for the distribution of costs associated with rectifying network problems to fall more heavily on households that do not have PV and storage installed. To address this, suppliers now charge a standing charge to customers so that PV and storage owners are seen to be paying their 'fair share'. Another concern for the market operator is the visibility of DER. Currently, the reporting requirements of the national-level revenue support scheme mean that the Australian Energy Market Operator (AEMO) has detailed information about the size, location and density of nearly all PV installations, providing it with important operational data. The same is not true, however, for battery storage. As there are currently no certificate schemes or tariffs for household batteries, if a customer installs a battery it is, for operational purposes, invisible to AEMO. Forecasting grid demand consequently becomes more difficult.

The rapid nature of solar PV expansion in Australia is challenging existing institutional arrangements, and has led to changes in the governance of the electricity sector being proposed by various stakeholders. This includes: changes in operational responsibility [74], a national register of small scale batteries and other DER [75], and limited changes to electricity market rules [76–80]. These changes have been needed to counter the challenges arising from the unexpected uptake of solar PV and domestic storage. However, they appear to be more of a reactive 'add-on' to the existing centralised arrangements than optimisation for a more decentralised system.

4.3. *Local vs national enactment on the island of Ushant*

The French island of Ushant (Ouessant) is a small settlement in the North Atlantic approximately 20 km from the coast of mainland France. Part of the region of Brittany but with no physical connection to the mainland, Ushant is electrically as well as geographically isolated from the European continent [81]. Until recently, Ushant derived approximately 100% of its non-transport energy needs from diesel-fired electricity generation at a single central plant: an arrangement which has long been understood to be both economically and environmentally undesirable [82]. Consequently, several attempts have been made to reorient the island's energy system towards one that is less centralised, more renewable and more flexible [81,82]. Despite some experimentation with wind energy in the 1980s, with no electrical connection to the transmission system of mainland France, until recently all electricity demand on the island was met from a single diesel fuel generation plant [83,84].

Ushant's location offers strong potential for electricity from solar, tidal, and wind energy [85,86]. Beginning in 2009, the Regional Council of Brittany initiated a series of actions designed to reduce dependence on diesel for electricity generation by moderating energy demand and expanding the use of renewable energy technologies [87]. The current ambition is for 70% of the island's electricity consumption to be sourced from renewables by 2020, rising to 100% by 2030 [88,89].

Electricity *costs* in Ushant are high and forecast to increase further [90]. However the current institutional context means that electricity *prices* faced by consumers remain the same as those experienced by mainland consumers with nationally regulated domestic tariffs[7]. The substantial difference is made up by a general levy or surcharge on energy suppliers, effectively socialising costs among energy consumers [90,91]. One consequence of this arrangement is to make electricity the heating source of choice, since its subsidised price outcompetes imported heating oil or other alternatives. Another is that consumers do not have financial motivation to drive a switch to renewables that might apply in other isolated locations with high energy costs [90,91].

The municipal agency *Syndicat Départemental d'Energie et d'Equipement du Finistère* (SDEF), which owns the distribution network, is legally responsible for the provision of energy services, and has a mandate to improve the environmental performance of the assets under its stewardship [89,92]. However, the current institutional arrangement means that virtually all distribution services such as network operation, maintenance, and expansion are conducted on a concession basis in which long term contractual arrangement places responsibility for large parts of the electricity system on a concession holder.

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[6] *Cost of a solar/storage system (based on Powerwall 2.0 cost) assuming lifespan of 10 years for both (after 10 years costs drop to $0), costs for PV taken from* Ref. [111] *and solar resource and household electricity use for each of the capital cities calculated for each of the NEM states taken from* Refs. [112,113]. *No allowance has been made for FiT payments to give an idea of the economics of disconnecting from the grid.*

[7] Eurostat table nrg_pc_204.

Many of the firms operating in the French energy sector, such as the transmission system operator, Réseau de Transport d'Électricité (RTE), and the largest distribution operator, Enedis, are 100% owned by state-owned monopoly *Electricité de France* (EDF) [93]. For example, Enedis currently holds the Ushant distribution network concessions (expiring in 2023) [94]. EDF, through one of its other subsidiaries, also owns the Ushant central electricity generation plant and is responsible for operating, developing, and ensuring the security of the electricity system in line with the same regulatory requirements as on the mainland [95].

Over recent years, there has been a growing impetus for change in Ushant's electricity system. In response to the regional government's plans for expanded use of renewables [87], the département, through SDEF and the non-profit *Association Iles du Ponant* (AIP) [96], has pursued various options for improving energy efficiency and expanding renewable distributed generation. A 54 kWh solar PV array was recently installed on the roof of a municipally owned sports centre by SDEF, and energy efficiency in Ushant has been somewhat improved [88]. In partnership with a number of business development associations, part of the strategy has been to couple energy system change with local economic benefits, especially the attraction of new entrants to the island economy [97].

However, SDEF and AIP have faced significant challenges in these endeavours. Firstly, it is apparent from fieldwork that the *syndicat* lacks the technical and material resources required to analyse, identify and implement solutions, requiring participation in EU-funded programmes to gain access to expertise. Secondly, local actors reports that where progress has been made it has generally without the support of the national energy companies which are at best indifferent to and at worst actively resistant to the aims of a decentralised, locally managed electricity system. SDEF and its partners have, for example, found it impossible to obtain even the most basic technical specifications and plans of the distribution network of which they are the legal owners.

Meanwhile, actors from outside have made substantial progress. In 2015, 2 km from Ushant, a prototype 1 MW tidal stream energy conversion device manufactured by Breton company Sabella was installed in 55 m of water in the *Fromveur* Passage, leading to some supply of electricity to Ushant [98–101]. In parallel to, but with no reference to the local and community-led efforts to reconfigure the electricity system on Ushant, the incumbent utility company has also made its own moves towards increasing the flexibility of the Ushant system by installing a large electrical storage device on the island [102,103].

Building on these efforts, in 2017 a consortium including a major French renewable energy developer (Akuo), a Breton marine energy technology company (Sabella), and EDF announced that they had secured funding from the French central government to design and implement a multi-turbine tidal energy array alongside new onshore renewables and electrical storage. This was perceived as something of a *fait accompli* from the perspective of other groups seeking a community-led approach to electricity decentralisation [104].

5. Discussion

This section employs the Geels et al. analytical framework outlined in section 3 to explore our decentralisation case studies in relation to transition pathways, and examines presumptions about alignments between decentralisation, democratisation, decarbonisation and institutional change.

5.1. Which pathway?

At present, there is notable variation in the pathway of each individual case study, as categorised according to the typology put forward by Geels et al. [42] as shown in Table 2. It should also be noted that as processes described in the case studies remain ongoing, leaving potential for pathway-switching in the future.

Table 2
A summary of the three case studies overall transition pathways.

Case Study	Overall transition pathway identified	Form(s) of Institutional change identified
Cornwall LEM	Local reconfiguration/ transformation	Incremental - layering and drift
Australia Solar PV	Substitution	Incremental - layering
Ushant	Local reconfiguration/ transformation	Incremental - layering

The Australian case provides a glimpse of steps along a possible *substitution* decentralisation pathway whereby incumbent actors are replaced or displaced by other actors. Storage firms such as Tesla can be observed playing the 'disruptor' role for which Silicon Valley technology companies have become synonymous [105], after a boom in solar PV uptake attracted sudden entry into the market of affordable in-home electricity storage. Energy consumers meanwhile, motivated by apparent concerns about electricity costs and reliability, took the opportunity to reduce their reliance on incumbent suppliers. With the rise of affordable storage, an increasing number of households - as many as 1 in 8 new installations in 2017 [74] - are also going one step further, installing both solar PV and battery storage that achieves near total levels of electricity self-sufficiency.

At its current stage of development the Cornwall case sits between two different pathways; displaying features of both without clear indication as to whether they are in competition or supporting co-development. On one hand there are elements of a *local reconfiguration* pathway present, particularly in the changing role of Centrica. Firstly, Centrica is playing a new coordinating role in the LEM trial. Secondly, Centrica has formed new relationships with a more diverse group of smaller actors, including start-up companies such as LO3 Energy [106], in order to access technologies and skills not currently held 'in house'. On the other hand the *transformation* pathway describes the reorientation of incumbent actors toward radical niche-innovations and new business models through diversification of their core business. This pathway perhaps better encompasses changes within a wider spectrum of incumbent actors who are LEM project partners; including Centrica, WPD and National Grid. It may also offer insights as to why these actors are proactively embracing a trial which presents an opportunity to shape change around emerging technologies and markets.

Finally, in Ushant there appear to be two pathways competing to emerge. The first is a *local reconfiguration* pathway in which local demands for change prompt incumbents such as SDEF and AIP to seek alliances with new entrants to the Ushant energy system, adding new decentralised technologies and incremental change in institutions and rules. However, at the same time (or possibly in response), a process of *transformation* is sought by the incumbent energy utility in which radical new technology is implemented with little need to change existing institutions or involve local stakeholders. That the *reconfiguration* pathway is struggling to emerge is likely due to the territorial and jurisdictional nature of the governance arrangements. While demand for change and the desire to engage new entrants in the process was present at a local level, the capacity of local actors to effect meaningful institutional change is sharply constrained by both the dearth of resources and the universal remit of the national and regional level actors.

5.2. Shifting rules and institutions

All three case studies demonstrate incremental change in rules and institutions. However, amongst the cases the reasons identified for incrementalism are largely context-specific, with limited cross-case similarities. Firstly, in the Cornwall case there may be limits to future institutional change. While dominant utility firm, Centrica is investing in the LEM trial, many of the institutional changes that would precipitate large-scale adoption of the kind of decentralised models under investigation seem highly disruptive to incumbent suppliers' (and DNOs') current business models. It seems likely therefore that incumbents are recognising the need to assess possible future pathways for their business portfolios in light of anticipated institutional change. However, any institutional change that is happening certainly appears gradual; constituted by incremental and *ad hoc* adaptions to accommodate the growing level of distributed renewable generation or application of novel digital technology. As such, rather than the springboard for disruptive change, it may be more accurate to view the LEM trial in one of two lights. Firstly, the LEM could be considered an exercise in competence adding, rather than major reorientation. This aspect can be seen as limited institutional change, or 'layering', with an anticipation of 'drift' once the outcomes of national-level initiatives on decarbonisation and future system operation cascading down from BEIS and Ofgem [20] have been implemented. Alternatively, one could take the view that incumbent companies' proactive investment in the LEM is evidence of desire to actively steer change in a manner that they may consider workable. If this is the case then in future we may expect to see Centrica, and potentially other comparable companies, engage more deeply in processes of facilitating institutional change. In the Cornwall case, the potential for engagement relates specifically to local energy markets, however further research is required to determine whether similar processes may be happening in other areas of the energy system affected by technological change.

In the Australia case, while subsidies for decentralised solar PV were initially centrally-led, the uptake of the technology was primarily consumer-led and vastly exceeded expectations. From a consumer perspective, uptake was fuelled by falling technology costs and government subsidies, but also driven by a need to reduce household energy costs and secure energy supply. This is reflected in the main demographic of purchasers being in the low to middle income level, or those who were asset rich but cash poor, such as retirees [107]. Institutional change following in the wake of the boom is, in general, modest layering in which the new participants must 'fit and conform' to the institutional environment. New rules, addressing concerns about the operation of a network in which large volumes of electricity are generated and stored by households, are currently in the process of being decided. While there is an appetite for change from many stakeholders, current governance regulations are more suited to efficient running of a centralised system. This is causing barriers to more wide-ranging governance change that could potentially support deeper forms of energy decentralisation.

Finally, Ushant provides a useful illustration of conflict between different territorial levels on the subject of energy system decentralisation. While dominant role of the national monopoly inhibits locally-led decentralisation efforts, the same monopoly is able to unilaterally introduce technical elements of decentralisation 'over the heads' of the affected community. Simultaneously, the national-level system of consumption subsidy through tariff levelisation prevents island residents from experiencing the 'underlying' economic cost of the existing system, potentially enhancing the dominance of status-quo actors such as EDF.

As highlighted in the table and analysis above, institutional change across all cases is characterised primarily by *layering* and in one case also by *drift*. These forms of change represent the most incremental varieties, tending to remain closer to existing rules and institutions that alternative process of *displacement* or *conversion* [30]. This is a striking finding, as the case studies demonstrate very different levels of technological disruption; from widespread change in Australia through to predominant continuity in Ushant. Institutional inertia is potentially a sign of policy playing 'catch-up' with technological advance, rather than acting as a facilitator for effective development, use and coordination of emerging technology and supporting infrastructure. While this area requires further research, it perhaps offers a warning to policymakers in other fields experiencing disruption; particularly emerging areas of energy system digitalisation.

The contradictions and conflicts identified above complicate assumptions that decentralisation will automatically lead towards changes in rules and institutions that are positive for other normative goals in the energy system. Rather, these case studies have highlighted how relationships between different actors and technologies have the potential to constrain, shape, or sidestep, change.

5.3. Pathways to … where?

Turning to the concept of energy democratisation, both the Cornwall and Australia cases illustrate growth in the number of decentralised actors and practices active at the domestic level of the energy system. Here the energy systems change to engage a more 'diverse participatory collective' [107 p205] of SMEs and households that are both producers and consumers of energy (prosumers), as well as traders in the case of the Cornwall LEM. Szulecki [2] p32] discusses how the prosumer figure has become an "idealized citizen of energy democracy", creating associated new political subjectivities that extend conceptions of energy democratisation beyond public participation in energy policy-making alone. This emergence of new, context-specific forms of prosumption in both case studies may initially suggest that processes of energy democratisation are taking place. However, the depth and focus of these processes is less clear.

In both cases, narratives surrounding new prosumer households also foreground their role as economic actors. Much less is discussed with regards to prosumer agency in decision-making; particularly in terms of decisions that go beyond exercising consumer choice or participating in peer-to-peer trades. This is significant as it omits the opportunity for smaller actors to engage in participatory governance; a key part of Szulecki's definition of energy democracy. For example, within the LEM case study Centrica is trialling a new means for smaller actors to access the electricity market, a route which has historically been reserved for large, centralised incumbents. However, Centrica retains the agency to determine how this market is designed; setting the 'rules of the game' albeit within the broader national policy and regulatory framework and defining the products that are to be purchased as well as who has access to this market. In this case new rules may be developed based on the results of the trial which increase domestic participation in a new form of 'decentralised' energy market. However, any changes seem likely to simultaneously allow Centrica to retain substantial aspects of a somewhat privileged position. This demonstrates the potential for distributed energy pathways to reproduce existing power dynamics, potentially limiting contribution to normative goals such as democratisation. This could itself be seen as a form a 'regime resistance' [108].

By contrast, the case study of Ushant portrays one instance in which there is explicit community interest in decision-making (i.e. in shaping the form of and rules governing island energy decentralisation), coupled with frustration that they do not have sufficient power to affect change. Despite this power imbalance between community and incumbent utility (EDF), elements of energy democratisation are arguably more clearly identifiable in this case study. Szulecki contextualises the emergence of energy democracy in a time period where mainstream models of democracy are being widely critiqued. This is resulting in new calls to amend deficits of democracy, accountability and justice in the energy sector which "was previously not seen as requiring public involvement, and was (is) most often depoliticized" [2] p27].

From this perspective, the explicit energy-politicisation of the Ushant community demonstrates processes of energy democratisation, despite a current lack of 'success' in gaining decision-making power. By contrast, case studies in Australia and Cornwall that demonstrate more extensive energy decentralisation involving a larger number of new energy actors may initially appear to hold significant democratic potential. However, the extent to which this may be exercised is currently largely limited to the economic realm; rendering participants more passive when it comes to their ability to shape broader normative questions and context of their participation in the energy system.

Finally, decarbonisation features as a broad theme across the three case studies above, as they are all contextually informed by targets to reduce power sector emissions. However, variation is displayed across and within case studies in terms of how different actors interact with decarbonisation; in some cases as a direct driver of innovation and in others as a more contextual informant of other technological and socio-economic change. A particularly diverse example of differing actor viewpoints is found in the case of Australia where, while incentives for solar PV installation are part of a national renewable energy strategy in conjunction with state-based schemes [49,68], the rationale given by household actors for installing solar PV is much broader; encompassing factors such as cost and reliability of supply. This suggests that, depending on contextual factors, energy decentralisation can be influenced by a variety of drivers that can be, but are not necessarily, environmentally-motivated. In addition, it is also important to recognise why and how drivers of decentralisation differ amongst actors, even within the same case study.

6. Conclusion

It is clear that there is, and will likely continue to be, multiple and sometimes conflicting interpretations of what energy decentralisation is or should represent. Decentralisation has numerous dimensions and what can be described as decentralisation from one point of view may be quite the opposite from another. Much of this arises from the multitude of interrelated innovations, both social and technological, that can serve as actors/props within a diversity of decentralisation narratives. Nevertheless, the 'decentralisation tendency' across its numerous uses tends to be associated with particular, often normative, outcomes.

The instances of 'energy decentralisation' examined in this article show that it *can*, but does not automatically, infer progress towards other normative goals within energy system change. Across case studies, transitions are happening in different ways, but the incremental nature of institutional change is a common theme. In the Australia and Cornwall cases, incremental change in rules and institutions contrasts strikingly to substantial advancements in the technological aspects of decentralisation. This is potentially a sign of policy playing 'catch-up' with technological innovation, rather than acting as a facilitator for effective development and use of emerging technology.

Energy democracy is, if it is to be genuinely democratic, necessarily 'political' and thus unpredictable; allowing for competing visions of the meanings and goals ascribed to energy decentralisation, and creating the potential for the continual negotiation and co-creation of any number of decentralisation pathways to play out. The extension of agency to new sets of actors within nascent energy markets can be considered an incremental step towards democratisation. However, as this agency is constrained by regime actors, a shift to democratisation as whole can be overstated. A key part of any meaningful concept of energy democratisation is the extension of rights and responsibilities to *shape* the rules of the game; not solely granting more actors more 'plays'.

However, this is not to suggest that incremental decentralisation is necessary slow. The urgency implied by the need to decarbonise energy systems, reflected in policies at all levels of governance, means that the energy-political context in the locations studied here is changing rapidly. Furthermore, the interplay between multiple, concurrent and complementary innovations, and the coevolution between this innovation ecosystem and energy-political contexts, offers potential for rates of change that exceed what has been witnessed in historic energy transitions [109]. In at least one of the cases above, experimentation by regime actors appears to be accelerating change through the active search for and experimentation with synergistic innovations, packaging them up to overcome specific local challenges. Importantly, these challenges are increasingly relating not only to the decarbonisation and decentralisation of electricity, but concurrent shifts towards low carbon and local heat and transport infrastructures.

In playing key roles in decentralised innovation experiments, regime actors are both actively and passively shaping what form of decentralisation 'works' in specific contexts. If we acknowledge that such appropriation affords actors power over the future rules and institutions of the energy system, there is an implied tension between forms of decentralisation based on technological innovation, and forms that emphasise the dispersed participation and decision-making commonly assigned to concepts of energy democracy.

The four pathways of socio-technical change proposed by Geels et al. provide some traction in the comparative analysis of energy decentralisation. In particular, by emphasising the path dependent and incremental nature of institutional change, the framework highlights consideration of the regulatory complexity that characterises much of the electricity system. However, to understand energy decentralisation more fully, a clearer specification would be useful in two areas.

First is the relative position of actors. The Geels et al. pathway framework allows for actors to be either 'incumbents' (itself somewhat loosely defined [110]) or new entrants (from within the system itself, or incumbents from other sectors). However, in the particular case of energy decentralisation, technical systems are highly stratified (into electricity distribution or transmission levels, for example), and shifting territorial roles may be the focus of institutional change. As such, a greater focus on actor *positionality* allowing differentiation between, for example, *types* of incumbent or new entrant could be a valuable clarification. Similarly, the framework, being based on theoretical insights built on historical observation, does not allow for the effective assessment of pathways against some of the normative goals discussed in this paper. The same perhaps applies to the inherently dynamic nature of the multiple innovations and actors involved in whole system transformation. Questions about which actors, enacting which types of decentralisation pathways, lead most reliably to preferred goals remain open.

Finally, while it falls outside the scope of this paper to prescribe a recipe for energy decentralisation, it is notable that none of the four pathways in the framework appear to 'fit the bill'; suggesting that they are non-exhaustive and do not encompass all possibilities. In particular, more work is needed to understand the ability of public actors such as communities, regulators and policymakers at all levels to overcome some of the limits to rapid institutional change Geels et al. describe. More research in this area may reveal other pathways or alternative patterns of democratic energy decentralisation, and provide insights about how existing tools of governance can be used now to shape them for the future.

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