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Vulnerability and resistance in the United Kingdom's smart meter transition

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A R T I C L E I N F O

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A B S T R A C T

The Smart Meter Implementation Program (SMIP) lays the legal framework in the United Kingdom so that a smart gas and electricity meter, along with an in-home display, can be installed in every household by 2020. Intended to reduce household energy consumption by 5–15%, the SMIP represents the world's largest and most expensive smart meter rollout. However, a series of obstacles and delays has restricted implementation. To explore why, this study investigates the socio-technical challenges facing the SMIP, with a strong emphasis on the "social" side of the equation. It explains its two primary sources of data, a systematic review of the academic literature coupled with observation of seven major SMIP events. It offers a history of the SMIP rollout, including a summary of 67 potential benefits as well as often-discussed technical challenges, before delving into pertinent non-technical challenges, specifically vulnerability as well as consumer resistance and ambivalence. In doing so, the paper not only presents a critique of SMIP, it also offers a review of academic studies on consumer responses to smart meters, an analysis of the intersection between smart meters and other social concerns such as poverty or the marginalization of rural areas, and the generation of policy lessons.

1. Introduction

By almost any standard, the smart meter program in the United Kingdom (UK)—known officially as the "Smart Meter Implementation Program" (SMIP)—represents a monumental undertaking. The SMIP lays the legal foundation to place a smart meter for electricity and for natural gas in *every* home and small business by 2020 (Smart Energy GB, 2017). It represents the UK government's "flagship energy policy" (Murphy, 2016a, 2016b: 2) and will involve installing a combined 104 million pieces of new equipment when counting separate electricity and gas meters, in-home display (IHD) monitors and wireless communications networks (Lewis and Kerr, 2014). The combined total cost is expected to be at least £11 billion, or more than £200 per household (Rose and Thed, 2014). Even the marketing campaign inspires awe, with £100 million committed over a five-year duration of the program, convincing Barnett (2015: 2) to estimate that it is the biggest advertising campaign in the world in the "next five years." Although the expected costs of the rollout are controversial, Lewis and Kerr (2014: 5) have argued that the SMIP is "by far the most complex" and also "costliest" smart meter program, as well as the largest government-run information technology project in history. Smart Energy Great Britain (Smart Energy GB), the "voice" of the smart meter roll out, framed it as "the biggest behavioral change program that this country has seen" (House of Commons Science and Technology Committee, 2016: 13) and "the biggest national infrastructure project in our lifetimes" (Smart Energy GB, 2017: 1). The Department of Energy and Climate Change (DECC, now merged with Business, Energy, & Industrial Strategy [BEIS]) argued that it is the largest transition the energy industry has undertaken in the UK since the conversion to North Sea natural gas (quoted in Darby, 2010).

However, implementation has been replete with obstacles, and progress sluggish at best. Although Smart Energy GB sold the program

Abbreviations and acronyms: AMI, advanced metering infrastructure; AMM, automated meter management; BEIS, Department for Business, Energy & Industrial Strategy; CALMU, Credit And Load Management Unit; DCC, Data Communications Company; DECC, Department of Energy and Climate Change; DNO, Distribution Network Operator; DTI, Department of Trade and Industry; ENIC, Electricity Network Innovation Competition; EDRP, Energy Demand Research Project; EU, European Union; ICT, information and communication technology; IHD, in-home display; LCN, Low Carbon Networks Fund; Ofgem, Office of Gas and Electricity Markets; SMCDB, Smart Meter Central Delivery Body; SMETS 1, Smart Metering Equipment Technical Specification; Smart Energy GB, Smart Energy Great Britain; SMIP, Smart Meter Implementation Program; UK, United Kingdom; VET, Visible Energy Trial

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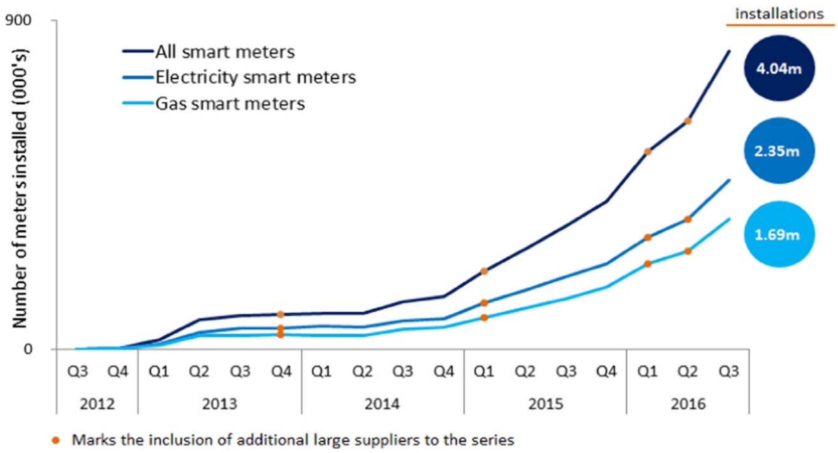

Fig. 1. Domestic Smart Meter Installations in the United Kingdom, 2012–2016.
Source: Department for Business, Energy & Industrial Strategy, 2017

on the grounds that it would enable "huge benefits for consumers and our national infrastructure" and facilitate a "revolution in Great Britain's national energy system," the SMIP has encountered numerous challenges (House of Commons Science and Technology Committee, 2016: 26). The program is years behind schedule and the costs of the rollout are highly contested. The start of the rollout has been delayed several times, from the initial 2014 starting date to November 2016. According to the most recently available Department for Business, Energy & Industrial Strategy data shown in Fig. 1, only 4.04 million meters have been installed as of late 2016, or 7.14% of the target number. In order to meet its targets, suppliers will need to install smart gas and electricity meters at a rate of about 40,000 per *day* for the duration of the program (Citizens Advice, 2017). Alongside this technical challenge, the SMIP also represents "one incredibly tough job" of convincing every household in England, Wales, and Scotland to install a smart energy meter (Barnett, 2015: 3).

Alongside the more frequently discussed technical barriers, what types of non-technical or social barriers has the SMIP encountered? How far have these issues been considered (or not)? What kind of possible implications arise from these considerations? To provide some answers, this study utilizes a mixed methods approach to investigate the socio-technical challenges facing the SMIP in the United Kingdom. The article first explains its two primary sources of data, a systematic review of the recent academic literature coupled with participant observation of seven major SMIP events in the UK. It then offers a history of the SMIP rollout before delving into two core themes, grouped under the headings of vulnerability and resistance. In doing so, it not only presents a critique of the UK's implementation program for smart meters, it also offers a review of consumer responses to smart meters, an analysis of the intersection between smart meters and other social concerns, and the generation of lessons for other smart meter programs.

The main contribution of the article is to inform current policies and practices concerning the SMIP and national energy policy attempts to decarbonize electricity and heat in the UK. The Committee on Climate Change (2016a) warns that current UK policies will fall well short of the fifth carbon budget by at least 100 million tons, a large amount (37.2%) given that the carbon budget expects to save only a total of 268.4 million tons by 2035 economy wide (Committee on Climate Change, 2016b). This means new measures must deliver further efficiency improvements (Staffell, 2017), especially in the domain of heating. We provide insight towards this goal by investigating potentially overlooked non-technical, or human and social, elements in convincing consumers to accept new technologies aimed at making homes and power networks more efficient, sustainable, and secure.

Additionally, the article contributes to debates beyond the UK. Some €51 billion will be spent on smart meter initiatives in the near future across the European Union (EU) (Darby, 2010). In 2013, only about 10% of households in the EU had a smart meter, but the European Commission has mandated that this number rise dramatically to 80% by 2020 (Viitanen et al., 2015). The European Commission (2017) reports that Member States have committed to rolling out close to 200 million smart meters for electricity and 45 million for gas by 2020 at a total potential investment of €45 billion. This study, however, elucidates some of the technical and social elements befuddling attempts to rapidly diffuse smart meters across homes and cities—findings that have relevance for those wishing to better understand the temporality and complexity of both national and household energy transitions (Sovacool, 2016).

2. Research methods

To collect data for our study, a systematic and extensive search was conducted for peer-reviewed academic articles on smart meters in the UK, published between 2008 and 2017, in addition to a supplemental collection of relevant government reports and media news articles. As Petticrew and Roberts (2006) and Sorrell (2007) note, systematic reviews improve the evidence base for policy analysis by enabling better specification and inclusion of a broader range of results (minimizing bias), enhanced transparency about the research process, and a research design that can be replicated.

In order to maximize the size of our sample of literature and develop a thorough review, we conducted a broad search of articles discussing any aspect of the SMIP or smart meters, from engineering and technology concerns as well as social, political, economic, and cultural dimensions. We searched five different academic databases, looking for several sets of keywords within full-length, English-language research articles. We searched article titles, abstracts, or keywords for the terms "smart meter" and "United Kingdom," "England," "Britain," "Scotland," "Wales," and "Northern Ireland". Table 1 summarizes the total number of articles collected from each database—with none excluded—including: Science Direct (15), SpringerLink (2), Taylor & Francis's Informaworld (19), Wiley Online Library (1), and Sage (10). All of the resulting 47 articles were analyzed, and assessed both for topical coverage (what challenges facing the SMIP did they identify, what socio-technical barriers did they discern, if any?) as well as lacunae (what gaps within the literature existed?).

To supplement this systematic review, the authors also attended seven smart meter events in the UK between September 2015 and

Table 1
Overview of Systematic Literature Review on the Smart Meter Rollout, March 2008 to March 2017.
Source: Authors' compilation.

Database	Results for "smart meter" and "United Kingdom"	Additional results for "smart meter" and "England"	Additional results for "smart meter" and "Britain"	Additional results for "smart meter" and "Scotland"	Additional results for "smart meter" and "Wales"	Additional results for "smart meter" and "Northern Ireland"	Total
ScienceDirect	2	3	5	2	1	2	15
SpringerLink	2	0	0	0	0	0	2
Informaworld (Taylor & Francis)	12	3	3	0	0	1	19
Wiley Online Library	1	0	0	0	0	0	1
Sage Journals	2	2	3	1	2	0	10
Total	19	8	11	3	3	3	47

November 2016. These events were searched from the Internet, and chosen because they were fairly large (a minimum of 50 participants and a full program), at a high level (held in London, with many senior policymakers or intermediaries present), open to wide range of participants (with representatives from energy and equipment suppliers, regulators, civil society, consumer groups, and other stakeholders) and verifiable (most had full transcripts, background materials and a briefing booklet). The events attended were:

- 15 September 2015, Policy-UK Forum "Smart meters, engagement, infrastructure and smarter markets";
- 15 October 2015, Westminster Forum "Smart energy networks: innovation, regulation and market competition";
- 1 December 2015: Westminster Forum "Next steps for smart meters: program delivery, technological innovation, and consumer engagement";
- 10 March 2016: Westminster Forum "Annual Review of Demand Side Policy and Smart Energy Developments";
- 28 April 2016: Westminster Forum "Next steps for UK domestic energy efficiency policy";
- 12 October 2016: PRASEG "Energy Revolution will be Digitised: Opportunities and Challenges of a Smarter Energy System"; and
- 24 November 2016: Westminster Forum "Implementing the smart meter roll-out: customer needs, industry priorities and future developments."

The observational evidence collected from these events is useful for aiding the understanding of contextual conditions and deeper dimensions difficult to collect in static sources such as written texts (Yin, 2003). Such participant observation data offers real-time, contextual data to complement the systematic review, and it also improves data triangulation and validity.

We determined that almost two-thirds (59.6%) of articles identified through the systematic review tended to discuss primarily technical challenges to the SMIP; and, of the seven events, all (100%) of them discussed technical matters in depth. However, based on this prevalence for an emphasis on technology, we also determined that at least two important gaps existed, receiving far less coverage: how social concerns and vulnerable consumers are considered (in fewer than 10% of studies in the sample) as well as how consumers and others may resist the adoption of smart meters (mentioned in fewer than 5% of the studies).

3. History and context of the Smart Meter Implementation Program (SMIP)

Before delving into the core discussion of the article—focusing on vulnerability and resistance—it is helpful to first offer a brief history of the SMIP. This section first summarizes the specific technologies being utilized before moving into the proposed benefits of the program and the timeline of the rollout. It finishes with a summary of the presumed primary culprit behind the SMIP's difficulties, challenges with the technology.

3.1. Defining "smart" technologies and meters

There is no universally accepted definition of what constitutes a "smart" energy or gas meter. Darby (2008) notes that the phrases "advanced meter" or "smart meter" can refer to a bundle of different systems including net meters, digital meters, automated meters, interval meters, new meters, retrofitted meters, two-way communication devices, monitors and displays, and more. Purpose and functionality generally distinguish "smart" meters from "dumb ones," that is, "smart" meters communicate electronically and via a network to suppliers or grid operators (Darby, 2010).

Interestingly in UK policy documents, a range of terminology (such as "new types of meters," "smart energy systems," and "smart meters") was used until smart meters became a more commonly used term from 2006 (Hielscher and Kivimaa, unpublished). In the UK, smart meters have come to mean meters that can both measure and store data at specified intervals, and act as a node for communications between supplier(s) and consumer(s) via automated meter management (AMM), an elaborate way of describing automated meter reading or remote meter diagnostics. A smart meter in the UK always has an "in-home display", or IHD, which refers to the device or monitor that connects with the smart meter and provides consumers with information about their energy consumption and costs (House of Commons Science and Technology Committee, 2016). The term "advanced metering infrastructure," or AMI, is meant to encompass the entire system of associated communications and infrastructure involved in supporting and facilitating smart meters (Darby, 2010). As Fig. 2 indicates, when one focuses on the entire web of AMI rather than only the meter itself, the SMIP involves the simultaneous conversion of smart electricity meters, gas meters, IHDs, and wireless area networks, as well as a network of households, data and communications companies, service users, and electricity and gas suppliers. To be clear, the UK is perhaps the only country in the world that conflates smart meters and IHDs together, where suppliers mandate that all customers who adopt a smart meter must also utilize an IHD, as well as a data hub. The UK is also unusual in pushing both separate electricity and gas smart meters.

3.2. Proposed benefits

Although they remain contested, the ostensible benefits of the SMIP stem in part from the inefficiency of most existing meters across the UK. One peculiarity to the UK is that many meters date back to Victorian times and the late nineteenth century; another is that they are often located inside homes, requiring household members to be present when meter readings are taken (Thomas, 2012). Both of these oddities lead to a significant reliance on estimates that are often inaccurate and inefficient, which contributes to poor-quality feedback

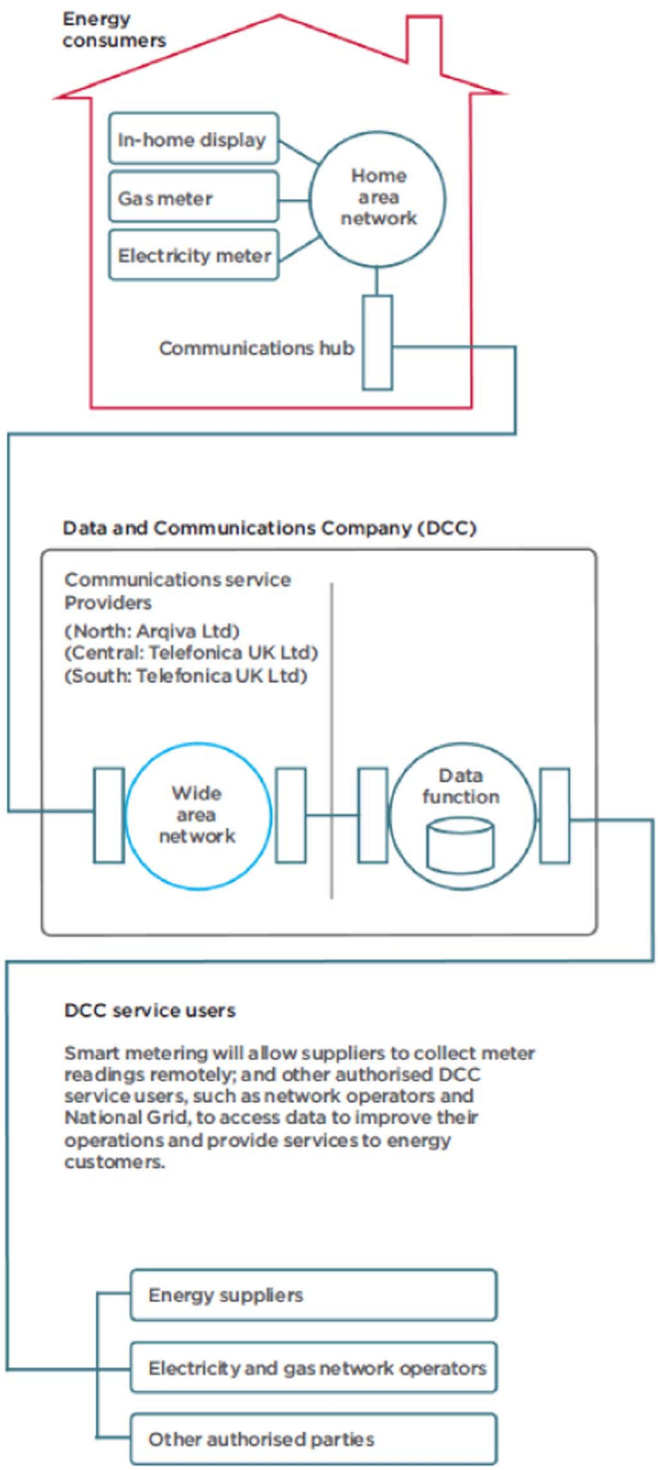

Fig. 2. The sociotechnical system for Advanced Metering Infrastructure and Smart Meters in the United Kingdom.
Source: Lewis and Kerr (2014).

in energy bills along with considerable customer dissatisfaction (Darby, 2010).

More than half of energy use within the UK is now in homes and personal transport, and electricity supply accounts for about 30% of the country's carbon dioxide emissions (Kotter, 2013). Yet by 2050, emissions from electricity must be reduced to close to 0% (Jenkins et al., 2015; Committee on Climate Change2016a, 2016b). In this context, a switch to smart meters offers the potential to capture numerous sustainability benefits. These include pricing signals that can reduce or at least better manage demand and encourage energy efficiency, as well as enhanced resilience by shaving peak load (or enabling demand side management or load management) and by making it easier to pinpoint and address power outages (Hess, 2014). Darby (2010) adds that offering direct consumption feedback to households and businesses—e.g., from a display rather than indirectly and mediated via the supplier in a bill or statement online—can also empower them to better manage energy flows, reducing or shifting demand as well as facilitating accelerated carbon reductions.

A recent House of Commons Science and Technology Committee report (2016) notes numerous other possible benefits distributed across consumers, utilities and society as a whole. For consumers, a fully functioning, user-integrated smart meter and IHD should enable:

- Easier switching between suppliers;
- More accurate billing, the avoidance of billing problems, and the need for meter readings; and
- Avoidance of debt accumulation through access to accurate near real time information.

For utilities and energy providers, it can enable:

- Removing the need for site visits to complete meter reads;
- Reducing call center traffic, with fewer queries about estimated bills; and
- Improved theft detection, debt management, and the ability for remote disconnection.

For society at large, it can enable:

- Benefits of optimizing electricity generation and network management;
- Reducing the need for a significant increase in reserve generation capacity;
- Transmission interconnection, network reinforcement and electricity storage;
- Technical innovation and the development of new business models and entrants; and
- Meeting binding climate change targets with less low carbon generation.

For perhaps some of these reasons, Utility Week : (2017: 1) suggested that the SMIP offers “an opportunity to transform transactional and largely negative billing interactions with customers into valued exchanges which deliver satisfaction all round, via reduced costs, improved transparency, and empowerment.” Buchanan et al. (2016) also surmised that smart meters could promote individual benefits such as increased awareness and consciousness about household energy needs as well as automation; community benefits such as comparing consumption with others or making new friends; or social benefits such as connecting with others and taking part in games and gamification.

Indeed, our own review of the literature identified no less than 67 overlapping short- and longer-term benefits summarized in Table 2. The Department of Energy and Climate Change (now transmuted into BEIS) estimated that the total costs of the SMIP would be around £8 to £11 billion, but the benefits could reach as high as £17.1 billion when one monetizes savings to consumers and suppliers as well as improved air quality, estimations summarized in Table 3. The UK Office for Gas and Electricity Markets (Ofgem, 2004: 2) projected that smart meters would deliver “sustained energy savings of 5–10% for many customers through the use of even a limited number of simple improvements.” Other studies suggested savings as high as 15% of consumption (Darby, 2006; Martiskainen and Coburn, 2011).

Looking to the future, the SMIP could achieve further benefits in the form of enabling virtual energy performance certificates for

Table 2
Sixty-seven anticipated short and long term benefits to smart meters in the United Kingdom.
Source: Author's compilation

No.	*Short term benefits*
1	Offer an alternative to pre-payment meters or bring down costs of pre-payment meters
2	Help consumers to budget
3	Increase energy efficiency awareness
4	Feedback on energy use
5	Carbon savings
6	Provide real time information energy costs
7	Provide information to make informed choices/ Greater understanding
8	Remote reading, avoid home calls
9	Energy bills accurate
10	Saving energy/ Reduce consumption
11	Manage their energy use, avoid waste
12	Customers install micro-generation
13	Remote switching credit and prepayment
14	Smoother switching between suppliers
15	Wide range of tariffs and incentive packages from suppliers
16	Suppliers to reduce costs
17	Customers save money/ Reduce costs
18	Better services from energy companies
19	Energy network planning
20	Drive uptake of renewable electricity
21	Reduce demand for heat
22	Billions in net benefits to the economy
23	Future Innovation
24	Jobs
25	Drive a more vibrant and competitive market
26	Offset price rises
27	Access a full range of energy management tools
28	Changing the way we think about energy
29	Help vulnerable customers
30	Pre-payment replaces by smart meter
31	Promote community energy
32	Consumers more active in the energy system
33	Suppliers offer more cost effective tariffs
34	Record how much consumed 1/2 h period
35	Promote distributed generation or distributed energy resources
36	One day switching
	Long term benefits
37	Demand side management
38	Reduce peak loads via time of day tariffs
39	Network reinforcement and peak generation avoided
40	Advanced management techniques/ Automated demand side response
41	Reduced energy consumption
42	Consumers more flexible and responsive to market signals
43	Smart grid
44	Electric vehicle promotion
45	Automated responses to changes in network
46	Enhanced monitoring flow across the network
47	Deal with intermittence
48	New products and services/ innovation
49	Vibrant, competitive market in energy supply and energy management
50	Improved network efficiencies
51	Uptake microgeneration
52	Turning off non-essential electrical appliances
53	Energy network management
54	Smart Energy Services supported
55	Smarter energy market
56	Network operators understand loads on infrastructure
57	Network operators plan investments
58	Network operators respond faster to supply loss
59	Avoid the need to invest in additional network/ and generation capacity
60	Generate capacity to meet peak demand
61	Support smart apps and automated appliances
62	Enhance resilience
63	New opportunities for storage
64	Consumers take advantage of lower price periods
65	Peak shaving
66	Develop a domestic smart appliance industry
67	Large industrial customers and small-scale generators capacity market

buildings, offering performance data on retrofits and new builds for energy providers (and researchers and policymakers), or even encouraging consumers to invest in energy retrofits, facilitating automated loads, or promoting the uptake of intelligent homes. The "big data" enabled by smart meters could allow the research community to better understand consumption patterns and behavior with high quality, robust analysis (Hamilton et al., 2013). It could also facilitate new business models that incorporate electric vehicles, heat pumps, and other storage devices in a "vehicle-to-home" or "vehicle-to-grid" configuration (Robinson et al., 2013; Poghosyan et al., 2015; Al-Wakeel et al., 2016).

3.3. History of smart meter rollout

Smart meters, or devices similar to them, have at least a thirty-five year long history in the UK. The historical narrative often dates back to the 1970s, when time-of-use pricing was developed as part of a Credit And Load Management Unit (CALMU) scheme that was trialed in 1981 but never adopted on a large scale (Thomas, 2012). In the 1980s, interests and developments in smart metering mainly derived from communication providers and the manufacturers of meters, pitching their "unlimited potential" (Marvin et al., 1999: 114). Utilities were rather disinclined to put their efforts into thinking about a large-scale smart meter rollout, doubting the environmental benefits and highlighting market uncertainties (Marvin et al., 1999). In 1990, the 45,000 largest industrial and commercial clients for electricity in Great Britain (with demand of more than 1 MW) were required to install smart meters capable of displaying time-of-use prices. In 1999, studying several options of smart metering systems, Marvin et al. (1999: 123) argued that 'a context needs to be created in which "dominant social interests", such as utilities, manufacturers and communications companies, can be supplemented with the "missing voices" of regulators and user groups'.

A commitment to modern smart meters in domestic buildings started to slowly emerge from the 2000s onwards with a renewed focus on energy security and climate change (Murphy, 2016a, 2016b), and the opening up of supply competition for households, plus the development of information and communication technology (ICT). "Three significant policy reports were produced on smart metering in the UK, but few notable new policy or regulatory responses emerged" (Owen and Ward 2006: 9). One of these reports was produced by the Smart Meter Review Group that was set up in 2001 by the Department of Trade and Industry (DTI), a precursor to both DECC and BEIS. They recommended that "pilot studies should be set up to establish how far smart metering could contribute to social, environmental, and security of supply objectives" (Darby, 2008: 74).

The beginning of the SMIP as we know it today is often traced to 2006. Driven by the European Union Energy End-Use Efficiency and Energy Services Directive 2006/32/EC, the UK government was busy debating which "forms of metering, tariffing and billing are feasible" (Darby, 2008: 70). A later Directive 2009/72/EC concerning common rules for the internal market in electricity stated that "where roll-out of smart [electricity] meters is assessed positively, at least 80% of consumers shall be equipped with intelligent metering systems by 2020". Furthermore, the uptake of renewables in the electricity sector started placing a renewed emphasis on sustainability, and discussions about electricity market reform emphasized competition and consumer choice.

In 2008, Gordon Brown's government announced its decision to rollout smart meters, including display units to all households by 2020. The announcement was made before the results of the government backed pilots to assess the benefits of smart meters, such as the Energy Demand Research Project (EDRP) from 2007 to 2010, were collated

Table 3
Projected Financial Benefits to the Smart Meter Implementation Program in the United Kingdom.
Source: Modified from the "central case scenario" in Department of Energy and Climate Change, 2014: *75 and 116).* Note ToU = Time of Use. UK = United Kingdom. CO2 = Carbon dioxide.

	Domestic (£m)	Non-domestic (£m)	Total (£m)
Consumer benefits (from energy saving and microgeneration)	4295	1437	5732
Supplier benefits (including avoided site visits, reduced inquiries etc.)	7970	295	8265
Network benefits (reduced losses, reduced outage notification calls, fault fixing, avoided investment from ToU (distribution/transmission) etc.)	877	112	947
Generation benefits (avoided investment in generation from peak shifting through ToU)	803	49	852
UK-wide benefits (including CO2 reduction, air quality)	867	440	1307
Total	**14,812**	**2333**	**17,103**

and the impact assessments were fully completed (Darby, 2009). The government also created a legal framework for the rollout by implementing regulatory changes using powers conferred on the Secretary of State by the Energy Act 2008 and later the Energy Act 2011 (BEIS and Ofgem , 2013). According to Marres (2012: 20), several controversies arose from the publication of DECC's Impact Assessment, surrounding issues such as privacy, efficiency, fuel poverty, and surveillance.

Since 2010, a substantial policy, technical and regulatory apparatus has been implemented, setting in motion the SMIP, starting off with a policy design stage (July 2010-March 2011), and followed by the foundation stage (March 2011–2016), and the rollout (November 2016-present). From 2011 onwards, concerns about the mass-rollout emerged, in particular through several parliamentary committee enquires (NAO 2011, 2014, PAC 2011, 2014, ECC 2015). In addition to rising costs, the rapid pace of technological change, data security, and efficiency of delivery issues, the committees pointed to continuing uncertainties over how customers might gain from the rollout. The National Audit Office pointed to potential consumer resistance to smart meters (NAO 2014). In 2015, the House of Commons warned that "without significant and immediate changes to the present policy, the program runs the risk of falling far short of expectations. At worst it could prove to be a costly failure" (2015:3).

During the foundation stage in 2012, Charles Hendry, the Minister of State for DECC, stated that the smart meter rollout would no longer be mandatory for all homes; homes could opt-out, they would not be "obligatory" and people were "not required to have one" (Orlowski and Ray, 2012: 2). Still, the Department of Energy and Climate Change (2013) reiterated that the aim of the SMIP was the rollout of 53 million residential and non-domestic gas and electricity meters by 2020 at a projected cost (at that time) of £10.9 billion, with the costs borne by consumers through their energy bills. In 2016, this was estimated to be an average of £215 per home per meter, including installation costs (House of Commons Science and Technology Committee, 2016: 9). Further complicating matters, the main installation was delayed twice (from its initial start in 2014 until November 2016). As of July 2017, confusion remained, with energy companies telling customers the smart meter rollout was "compulsory" but others, including Queen Elizabeth II, indicating only that they would be "offered" to every home (Meadows and Brodbeck, 2017).

In terms of implementing the rollout, the UK government has made energy suppliers responsible. This in itself raised a problem given that supply competition meant that different households in a street bought their electricity from different suppliers. Hence, placing the responsibility on suppliers increases costs for installation since it cannot be done on a standardized, street-by-street basis. The control of the smart metering communication system has been delegated to a licensed private organization, the Data and Communications Company (DCC), who will form contractual ties with the suppliers (Bellantuono, 2014). Energy suppliers are intended not only to install the technologies (i.e. smart meter, in-house display and digital communication hub) but to convince householders into using them as outlined in DECC's Consumer Engagement Strategy (DECC, 2015a, 2015b).

The technical specifications of smart meters were converted into the "Smart metering equipment technical specifications" (SMETS 1) in 2013 (DECC, 2013c) and later on into SMETS 2. The Smart Meter Central Delivery Body (SMCDB), an organization established to increase public awareness about smart meters, was created along with the beginning of a marketing campaign lead by Smart Energy GB ("the national campaign for the smart meter rollout"). The latter featured advertisements with personified units of gas and electricity ("Gaz" and "Leccy") such as those shown in Fig. 3, disseminated via television, print, and email (with one campaign even targeting the London Underground, or "tube"). Adoption is expected to occur in "every home", though Smart Energy GB (2017: 1) has more recently emphasized that the SMIP is only for households "that want one," or that "everyone will be offered the opportunity to upgrade to a smart meter," giving them the option of not participating.

This characterization of the SMIP oversimplifies some of the complexity behind the project. As Jenkins et al. (2015) note, although Smart Energy GB is now the primary custodian of the rollout, a range of other actors have been supportive or deeply involved with smart meters over the previous decade, especially DECC (now BEIS) and the Office of Gas and Electricity Markets (Ofgem) as well as major energy suppliers such as SSE and British Gas. Ofgem's price control model, for instance, generally supported network innovation; and the creation of a £500 million Low Carbon Networks Fund (LCNF) and its successor, the Electricity Network Innovation Competition (ENIC), as well as the Network Innovation Allowance and the previous Innovation Funding Incentive. These sources offered funding for suppliers and network companies to invest in basic research in an attempt to catalyze smart meter innovation.

3.4. The presumed culprit: technical difficulties

The most frequently discussed reason for the difficulty of the SMIP rollout relate to the technology. Indeed, across the systematic review of 47 articles, 28 mentioned challenges – and all 28 discussed some element of "technological", "technical," or "engineering" impediments. Rose and Thed (2014) argued in a popular media story that numerous interconnected difficulties arose after the launch of the first phase, graphically illustrated in Fig. 4.

For instance, the meters available in 2014 would not work in a third of British homes, including high-rise flats, basements and those in rural areas. Rather than selecting the more customary Wifi or Bluetooth standards, the UK chose a less-known system called ZigBee which did not work well in high-rise blocks, because meters tended to be located in basements, and it struggled to penetrate thicker walls. As a result, costly alternatives for communications and network control were tested, including hardwired connections (via cable) as well as the creation of home area network radio systems. Some, such as Lewis and Kerr (2014), have proposed that the SMIP abandon attempts to stretch the rollout to flats and tower blocks altogether, removing 7 million homes from participation. Even a government Impact Assessment admitted the wireless coverage may be "difficult to achieve" in remote or mountainous districts (Rose and Thed, 2014: 3).

a. Top panel: Television advertisement, March 2016

b. Middle panel: Print advertisement, May 2016

c. Bottom panel: email advertisement, April 2017

Fig. 3. Smart Meter Implementation Program Advertisements.
Source: Authors' compilation.

This proved to be true, with a tenth—134,000 of the 1.3 million new "smart" meters installed in the UK as of early 2015—only functioning as traditional meters, requiring manual readings due to these limitations (Gosden, 2015b). That same year, two main suppliers also reported billing and technical glitches with substantial numbers of their meters—with OVO Energy (a gas and electricity supply company) reporting faults (where customers unable to view or pay their bills) across 6% of the meters installed, and EDF reporting problems with 0.5% of meters installed (Palmer, 2015a).

These technical faults led to the media reporting that hundreds of thousands of households were "trapped" with malfunctioning meters, reports of wild swings in how metered energy usage was displayed on IHDs, and (perhaps understandably) a large backlog of customer complaints (Shannon, 2015). These so-called teething problems were only worsened by reported incompatibility in meters between suppliers—meaning if a household wanted to switch to another energy supplier, once they switched they had to wait (in some cases more than a year) for a new meter. This also meant that switching suppliers had the effect of converting smart meters back to the "dumb" types that relied on manual readings or estimates (Palmer, 2015b; Meadows and Brodbeck, 2017). Other customers reported that the smart meters no longer worked when households changed their tariffs *within* a particular supplier (Brignal, 2016).

Furthermore, it was mentioned at more than one-third of the public events attended by the authors that hackers and cyber-terrorists had the potential to break into the system to disrupt the reliability of the grid or carryout theft or fraud by intercepting bills and private data. One potential risk is that "rogue programmers" in metering companies insert code that they then use to sabotage the grid, or to make ransom demands against companies (Clark, 2016). The House of Commons Science and Technology Committee (2016: 69) added that "disruption to energy and gas supplies at a massive scale is possible". Ofgem (2010) similarly warned that cyber threats range from fraudulent transactions for financial gain to compromise of critical operations such as remote disablement.

Most recently, in 2017, installation failures remained commonplace. Market research from Utility Week (2017) suggests that more than 10% of homes required and will continue to require multiple visits to complete installation of smart meters. The reasons for "installation failure" range from customers not being present and installations taking longer than expected, to meters not being accessible or a considerable distance apart, or to difficulties with multiple occupancy properties. These installation challenges alone are projected to inflate the total cost of the SMIP by as much as £1 billion (Utility Week, 2017: 4).

Other technical problems relate to the IHDs. Buchanan et al. (2015) emphasize that IHDs "work" and save energy only if users properly engage with them, and that the particular IHDs involved in the SMIP had a problem of a time delay in showing real-time prices and then in translating that data into reductions in demand. Indeed, such problems continue into 2017, with Fig. 5 showing faults in natural gas IHDs. Moreover, even when they work properly, consumers can lose interest in the real-time data, with British Gas reporting that after one year, only 60% of respondents in one of their smart meter surveys indicated they still look at their displays once a month; OVO Energy also found that after one year, only 60% of households still used their IHDs (Lewis and Kerr, 2014).

Such challenges have provoked some, such as Lewis and Kerr (2014), to argue that the IHD requirement be removed from the SMIP and replaced with an app that would let phones, tablets, and personal computers capture meter readings and connect to the network with no additional hardware cost. They note that the IHD requirement alone will cost roughly £800 million in total. Viitanen et al. (2015) concurred and emphasized in their study of customers in Sheffield and Leeds how smartphone apps were much easier to use, and more compatible with

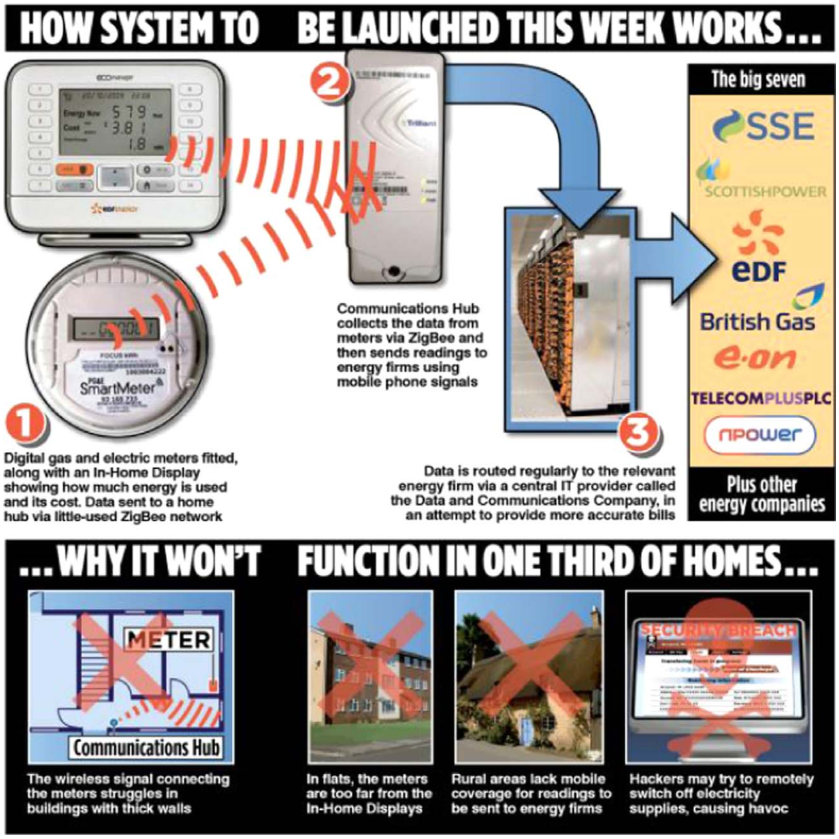

Fig. 4. Technical challenges facing the Smart Meter Implementation Program.
Source: Rose and Thed (2014)

lifestyles, than an IHD. Thomas (2012) points out that even in 2012, multiple devices existed which could identify and display consumption information about electric appliances at a much cheaper cost than a smart meter or IHD. The OWL, for example, was (at that time) a simple, £40 plug-in device that records and displays energy use over time, giving consumers "a clear, accurate picture of their energy use" (Thomas, 2012: 1061).

4. Vulnerability and resistance in the UK's smart grid economy

Notwithstanding the long history of smart meter development within the UK, and due in part to the technical challenges previously identified, the rollout is currently proceeding at a pace far slower than expected. The National Audit Office (2014), a public spending watchdog, said in a report that it would likely cost consumers £1.5 billion more (13.6%) than the expected £11 billion. As it noted: "Significant risks remain, including potential consumer resistance to smart meters, technical issues, the readiness of suppliers, network operators and the supply chain for large-scale installation and the robustness of data security and privacy arrangements." Plans to create a Data and Communications Company were delayed twice; one of the smart meter providers, E.on, was fined £7 million for its own late rollout (Murphy, 2016a, 2016b) and British Gas was similarly fined £4.5 million for their slow rollout a few months later (Ofgem, 2016). A group of Members of Parliament said on record in 2015 that "we do not believe that near-universal smart meter rollout will be achieved by 2020″ (Gosden, 2015a: 2). As even the Director of Marketing at Smart Energy GB now admits, it faces the difficult task of "shifting people from a position of absolute disinterest and apathy to a position of positive, enthusiastic engagement" (Barnett, 2015). One of our colleagues put it to us this way:

> *There is nothing for me as a consumer to be enthusiastic about the SMIP, aside from the IHD. If I'm too busy to study my IHD because the time/saving trade-off doesn't work for me, then what else is there? I'm a busy, reasonably wealthy person. My time is worth far more to me than saving a few pence on my energy bill. SMIP doesn't allow me to do things I would be genuinely enthusiastic about, like sell energy to the grid or participate in a demand response market or measure the performance of my home, or heating system, or anything, really. So I don't care. Because you aren't offering me, the customer, access to any benefits. In short, why would a program that offers little or no benefit to consumers, be received with anything other than apathy, at best? From a consumer point of view, the SMIP is a solution in search of a problem.*

This difficulty is only accentuated when one considers the problem of misattribution: Smart Energy GB surveys suggest that while 84% of customers say that they have "heard of a smart meter," when asked clarifying questions to test that knowledge, "true awareness" drops to less than 20% (Barnett, 2015). Part of the explanation may lie in the very common confusion between a smart meter and an IHD, with one being a system element, the other a personal device or tool.

These complicated dynamics underscore the social dimension to some of the most pressing challenges facing the SMIP. To provide a more complete explanation for why the SMIP has faced such difficulties, this next part of the study offers our findings from both the systematic review of academic literature and our participant observation. It is organized roughly across two dimensions of sociotechnical barriers: the intersection of the SMIP with the enhanced vulnerability of some types of customers; and active "resistance" or "ambivalence" among some households and other key stakeholders. Table 4 offers a summary of where these themes sit alongside the more frequently discussed technical barriers to the SMIP.

Fig. 5. Technical Fault with Natural Gas In-Home Display showing Incorrect Data, April 2017.
Source: Authors' compilation from SSE website, April 10, 2017.

Table 4
Dimensions of technology, vulnerability and resistance in the Smart Meter Transition in the United Kingdom.
Source: Authors

Dimension	Barrier	Explanation
Technical	Limited range	Smart meters dysfunctional in high rise social housing complexes, basements, or rural areas
	Malfunctions	Glitches in software concerning energy estimation, metering, and billing as well as faults with IHDs and installation failures
	Incompatibility between suppliers	Requirements that consumers purchase a new meter if they switched suppliers or even altered their tariffs on existing suppliers
	Hacking and cyber-terrorism	Concerns over accessibility of personal information or intentional sabotage
Vulnerability and poverty	Consumer misunderstanding	Confusion over proper use of smart meters among the elderly, poor, or non-English speaking population
	Financial burden	Expense of installing smart meters placed on consumers
	Rural peripheralization	Social marginalization of rural groups and a preference for channeling smart energy systems to urban areas
	Externalities	Lifecycle impacts such as embodied emissions and electronic waste
Consumer resistance and ambivalence	Defiance	Users inputting false data or intentionally misusing their smart meter
	Privacy	Perceptions that smart meters extend competitive interests (companies/utilities) into the home or enable government surveillance
	Health	Beliefs that smart meter wireless networks can expose people to non-ionizing electromagnetic fields
	Apathy	Consumers expressing disinterest or apathy with smart meters, with little concern over monitoring or reducing energy use

4.1. Vulnerability and poverty

One major dimension of obstacles relates to the exacerbation of vulnerability among some classes of customers—notably burdens upon the elderly, the ill, the less educated, those in social housing, and/or those in rural areas—and a preference for economic competition and cost savings for suppliers and companies, not households. In theory, if the SMIP can reduce costs in meter reading, network operation, grid reinforcement, electricity generation and so on, then consumers overall benefit from lower energy prices - regardless of whether they make any behavioral changes. In practice, however, multiple dimensions of vulnerability become apparent within the material we examined.

For example, a comprehensive synthesis report from (DECC, 2015a, 2015b) involving a survey of 4016 consumers, in-depth interviews with 169 households using both credit and prepayment meters, 12 focus groups and analysis of consumption data for over 10,000 households concluded that consumers from vulnerable groups "are likely to need more help if they are to obtain the full benefits of smart metering" (DECC, 2015a: 22). It noted that "older smart meter customers, those from lower social grades, those with the lowest total annual household incomes (below £16,000), those with no formal qualification and those who lived with someone who had a long-term health condition or disability were less likely to say the IHD was easy to use or to say they knew how to operate its different functions" (DECC, 2015a: 22–23).

Barnicoat and Danson (2015) utilized sensors and IHDs to measure and display energy costs for households with elderly tenants in rural Scotland. Elderly tenants are of particular concern given that they tend to spend a greater amount of time inside their homes; utilize more domestic energy; may be on fixed incomes prone to fuel rationing and need greater warmth with older age, and may also suffer physical limitations that inhibit their interaction with equipment. Their study investigated how such households interacted with IHDs (or "smart energy monitors") for seven months. It found that despite the enhanced feedback about prices, little "awareness" occurred—households did not "really understand" the relationship between the IHDs and electrical appliance use, with one participant even indicating she did not know what the "traffic lights" were supposed to refer to. Another indicated: "I have got a wee display there, but to be honest I never even look at it, do you know this I can not be bothered." A third participant confused what the lights on her IHD meant, thinking that a red light was a "warning" and that they were in "danger," and shutting off her kettle every time she saw it, when that light merely indicated that the level of kWh being used had increased. Moreover, the study suggested that the primary benefit of the IHDs was perceived to not be for households, but the engineers working for energy suppliers—giving them information about household use—which was at odds with consumer expectations. In sum, the study concluded that even with information sessions and IHDs, elderly participants showed little knowledge or interest.

Citizens Advice (2017) echoed similar concerns in a report critiquing the SMIP for its negative impacts on the elderly and low-income households, particularly those with no formal education, those who do not speak English as a native language, or those with a long-term illness. It noted that such customer classes remained confused about, distressed, or unable to use the information offered by smart meters. Liddell (2015) also emphasized that for smart meters to effectively save energy in rural areas or social housing blocks, significant targeted outreach efforts are needed, as demand reduction in particular requires "sustained vigilance and adaptation from the occupants, particularly in the first year."

In the events observed by authors during 2015–2016, several charities and NGOs pointed to challenges associated with the rollout vis-a-vis vulnerable people (but also advocated the rollout). For instance, one participant from the National Energy Action (NEA) said in November 2016 that "I think some of you may find it a bit strange that, as a national charity committed to tackling fuel poverty, that we want to put an automatic meter in someone's home… and then provide that information straight back to a supplier for them to be billed in a more efficient manner". Charities and NGOs recognized the challenges ahead in November 2016 but were still hopeful that the rollout could provide benefits to vulnerable groups: "I think that we feel that we've got a job on our hands", making vulnerable people aware of the potential benefits of smart meters. Smart Energy GB and the Department for Business, Energy & Industrial Strategy (BEIS) seemed to be less reflective about the potential challenges ahead for vulnerable groups and argued that they had dealt with most of the associated barriers. For instance, Smart Energy GB argued throughout that the smart meter advertising campaign was working for vulnerable people, stating that "we are very happy to see that our messages are resonating even more strongly with those living in fuel poverty" (Smart Energy GB, November 2016). While Smart Energy GB is essentially a marketing organization, operating and communicating as such, it is worth noting that their CEO has a background that includes work with Citizens Advice.

An analysis of the events data further draws attention to a potential mix of responsibilities to make sure vulnerable groups benefit from smart meters. Smart Energy GB talked about "a shared responsibility with suppliers around behavior change" (Smart Energy GB, November 2016), but how this responsibility is shared seems to be unclear. There was also talk about "partnering up" between organizations to support people so they could "make use of the benefits" and of "mobilizing" energy champions, volunteers, and a community fund that could aid the experience of vulnerable groups. However, there seems to be no real conversation surrounding who will organize or guide these activities or how these activities will be combined with the main installation across the UK. This could be what provoked DECC (2015b) to request Smart Energy GB to develop better advisory and other supporting materials; mobilize, support, and coordinate local networks and partnerships; and act as a facilitator for knowledge exchange.

Notwithstanding such rhetoric about political or social inclusion, we note that one further economic drawback to the SMIP revolves around the fact that some smart meters can create net burdens. In their cost-benefit analysis, the National Audit Office (2011) emphasized that the rollout would deliver savings to energy suppliers but its empowerment of consumers was more uncertain—especially given that the costs of the program will be passed directly onto consumers. The overall benefit to households also depends on the extent to which suppliers minimize costs and pass on savings to customers—which is not guaranteed. The Public Accounts Committee (2012) of the House of Commons noted similar concerns in their report: that consumers will have to pay suppliers for the costs of smart meters, but most benefits will be distributed to suppliers; that the benefits of smart meters only occur if there is widespread adoption (not a given since consumers can "opt out" of the SMIP as of 2017) and "correct" usage; and that benefits will likely not reach vulnerable customers or those using prepayment meters. Zhang and Nuttall (2011) modelled four different deployment options for the SMIP, two government led (competitive, monopoly), one led by suppliers, and one led by Distribution Network Operators (DNOs). They found that the government chose the *least* effective rollout option from the standpoint of both overall cost and maximum benefits for households, i.e. a pathway that will benefit "only a very small number of consumers who really care about smart metering." This involved a competitive model passing on costs to customers to preserve the ideal of market competition and to avoid the risk of increasing the deficit for the Treasury. Such burdens become even more apparent when one considers the needed cost of £430 per household for two gas and electricity smart meters being passed onto consumers directly.

While elderly people have been perhaps the most discussed in connection to SMIP, there are at least two instances of increased vulnerability that are less frequently documented: (1) increased rural peripheralisation and (2) externalities and lifecycle impacts. Rural peripheralisation refers to the worsening of the urban/rural divide, or increased preference for a smart meter roll out in cities, but not homes in the countryside. Blowers and Leroy (1994) explain that this occurs within communities "located on the edges of the mainstream" as they are either geographically remote, or are isolated as an outcome of uneven political, economic, and cultural domination and exploitation. Rural homes are, to a certain extent, already marginalized. In only one of the smart meter events was a brief reference made to rural areas. For example, in Scotland, access to fixed broadband services–a prerequisite of a functioning Smart Meter system–is 69% in rural areas, and 80% in urban areas (OFCOM, 2016). In addition, the housing stock is physically more challenging to access, meaning that the roll-out requires more person hours and travel mileage. Combined, this leads to a perhaps understandable, but not socially equitable, focus by suppliers on "easy to manage" urban areas with large volumes and better established delivery and logistical networks, leaving rural communities increasingly isolated from digital innovations.

Secondly, limited attention has been paid to the hidden social and environmental costs, or externalities and lifecycle impacts, of the rollout and how this impacts on vulnerable people outside the UK. The focus of the roll-out is predominantly on new, advanced technology and its potential impact on carbon savings, but this neglects the electronic waste that results from the removal and replacement of millions of old (and soon to be obsolete) meters and the lifespan of new IHDs. It is likely for instance that the IHDs and smart meters will not last as long as the older meters which have been in place for decades. A search of information in the public domain indicates few transparent plans to repurpose and recycle this equipment. Much of the world's obsolete equipment currently ends up in electronic waste dumps, including those in Ghana, with local environments suffering from toxic environmental damage as a result. Moreover, there seems little attention to the downstream and upstream international impacts of smart meter construction and distribution. Smart meters contain heavy metals mined overseas in countries with comparatively lower environmental and social standards. The result is the potential externalization of environmental and social costs, and potentially even carbon costs. For instance, Louis et al. (2015) conducted a lifecycle assessment of an entire home energy management system, including a smart meter, home automation, and IHD. They concluded it had a negative energy payback ratio of 1.6 years—the system as a whole was a net consumer, rather than saver, of energy. This was not an issue raised at the events attended by the authors.

4.2. Consumer resistance and ambivalence

Another class of barriers relates to households and consumers more actively resisting the SMIP. Pullinger et al. (2014: 1158) write that "the SMETS standards have been developed in a largely top-down industry-led process with little input from, or attention to the householder". The lack of consumer interfaces into the technical specifications of smart meters seems to be at odds with the repeated narrative of consumer benefits being at the heart of the rollout.

Perhaps because of this disconnect, Chilvers and Longhurst (2016: 596) note that during one of the trials, the Visible Energy Trial (VET), people "resisted" by refusing to utilize their smart meters properly, which delayed the compilation of data and results and convinced others to drop out of the trial. They suggest at least two reasons for such resistance: the IHDs did not result in significant examples of behavior change or reconfigurations of consumption in ways that meaningfully saved energy, i.e., it was seen as incremental and therefore inconsequential; and participants felt the monitors put an unfair burden on households to take responsibility for carbon reduction compared to other actors such as industry or government. In this way, the non-adoption of smart meters can symbolize the "rejection of innovations" and feelings of disinterest and disenchantment (Kahma and Matschoss, 2017).

In their comparison of smart meter perceptions in Europe, Balta-Ozkan et al. (2014) found various dimensions of resistance framed in terms of accountability and responsibility. In focus groups across the UK, they noted that smart meter users held expectations that the government should be the one taking action to address climate change, not individuals. Users also resisted IHDs and smart meters for reasons of control and privacy – households viewed the smart meter merely as an extension of power companies into their private lives and domain of the home. The UK focus groups of users revealed that the potential of smart meters to "compromise security" and "invade privacy" became a recurring concern (Balta-Ozkan et al., 2014: 1185). One participant noted that "this is the sort of data I suppose you would not want anybody to get hold of;" another likened smart meters to the idea that "Big Brother" was watching them (Balta-Ozkan et al., 2014: 1185). Savirimuthu (2013) warns that the SMIP can even be interpreted as an "information panopticon" which gives government or corporate entities significant access to private consumer data, with limited principles of data protection or security of the personal information of consumers.

Bradley et al. (2016) noted that another level of resistance relates to the devices being potentially managed by the smart meters. Participants at a trial on a university campus indicated they were amenable to automated control or improved efficiency (and perceived reduced performance) for items like lighting and office equipment, but not for computers or computer monitors.

Others vented their frustration with some of the technical problems described above by overriding the system or undertaking inefficient behavior. In their focus groups with consumers, Buchanan et al. (2016) found that some expressed displeasure about the idea of energy suppliers managing consumption for them, and the perception that smart meters could lead to a decline in comfort and disrupt household routines. They also noted that "all of our focus groups" expressed suspiciousness and mistrust about the energy suppliers in charge of the smart meter rollout, with "several participants" suggesting that suppliers would somehow profit from the interest on household energy savings, or implement new time-of-use rates that would increase the price of electricity or gas when consumers most likely needed it. This complements a Smart Energy GB (2015) survey which found that 51% of a nationally representative sample of British respondents did not trust energy suppliers. One implication here is that some or perhaps even many households will opt-out of the SMIP. Another is that those feeling coerced into participating could be loath to share their data with "conniving" companies and may manipulate or sabotage their smart meter, or merely disconnect their IHD.

Others may resist smart meters for reasons of health. In his comparative assessment, Hess (2014) noted that although privacy and security concerns remained paramount, opponents also expressed issues over the health effects of wireless smart meters and non-ionizing electromagnetic fields, which transmit frequent signals through microwave radiation.

In practice, these various reasons translate into consumer resistance to the SMIP. Rose and Thed (2014) report worries among one supplier that "up to 20 per cent of customers will refuse to have smart meters installed" and two firms have documented additional costs from dealing with "reluctant customers." Vallés et al. (2016) add that smart meters are also seen as a threat to operations by some DNOs, given that it can radically reconfigure their business operations, requiring them to increasingly manage demand and the connection of new loads differently. In some cases, smart meters are credited with actually *increasing* consumption—in one of EDF's early trials in 2004, gas consumption rose among households by "almost 50%" as it made users aware of considerable under-heating (MacDonald, 2007).

In the events observed by authors during 2015 and 2016, consumer resistance did not come up as a specific topic of discussion, although a fair amount of attention was paid to data privacy and access issues. What is striking is that there was practically no focus on what consumers actually want(ed), with the exception of a National Grid speaker questioning, "can they manage to deliver what customers and consumers want at the end of the day?" (October 2015). The events perpetuate a view that the smart meter rollout is about increasing information for consumers to encourage them to change their own behavior (one way influence), rather than creating a new smart energy system involving consumers as more active participants with two way influence over what the future system will look like. Such a limited view of the consumer could explain the lack of interest or even elements of resistance we uncovered in our systematic review.

Throughout the events, terms such as "consumer benefits," "protection," "engagement," "enabling" and "empowerment" were frequently used without going into detail about what will happen after consumers are enabled and empowered. Only a few referred to consumer experience, trust and acceptance. Smart Energy GB noted in December 2015 that "consumer trust in the industry is not fantastically high at the moment, it is rising". Further, an official from an energy supply company remarked in December 2015 that "we have talked about trust, to me this is absolutely vital for future proofing, if we do not get off to a good start, with a good end to end customer experience, we will lose people's trust". In the last event observed, in November 2016, "consumer acceptance" was brought forward as one of the three remaining key challenges to the rollout, where Smart Energy GB stated that "There is no mandate on the part of the consumer although there is mandate on the part of the energy supplier. And that is a real challenge I think for a consumer engagement campaign, how do we make sure every consumer is empowered to say 'yes.'"

While many users may never actively resist smart meters, they may express ambivalence that compromises the effectiveness of the SMIP. Groves et al. (2016) argue that consumer segments are not uniform, and hold different cultural interpretations of the smart grid, smart meters, the smart city, and other imaginaries or visions of "smartness." In various interviews, they noted that many users express an ambivalent attitude towards the value, service, and learning opportunities smart energy systems may provide. Such ambivalence is especially strong among elderly participants, who presented a narrative orientated by life after the Second World War dealing with scarcity and the emotional and symbolic rewards of visible energy consumption, notably the provision of heat and light from fires and natural gas boilers. Here, smart systems are seen as a way of making this consumption even more automated, and removing control from the person to the technology, creating "friction" with personal identity. Liddell (2015) notes that this combination of resistance, ambivalence, and other factors likely explains why it is so difficult to translate smart meter adoption into efficiency savings. The most successful reductions in consumption require a complete change in lifestyle and sustained "vigilance" that many households do not possess or want to possess.

Admittedly, resistance and ambivalence do not always or even frequently occur. A commercial survey in 2017 of more than 1000 consumers in the UK suggested that 64% of those with meters in place were "enjoying better visibility of their energy costs, 36% said they had achieved savings and 76% said they were impressed with the technical and service expertise of the individuals who completed the installation" (Utility Week, 2017: 2–3). But even if they remain an exception rather than the norm, for perhaps these reasons of resistance and ambivalence, some or even many consumers with smart meters saved far less energy than predicted in the trials at the start of the SMIP. The top panel of Table 5 shows how smart meters using in-home displays did not significantly reduce consumption in the United Kingdom (and elsewhere in Europe), with most studies showing only a 1–3% reduction. The European Commission (2017) reports that across the EU, smart meters result on average in 3% energy savings.

The bottom panel of Table 5 shows how the reductions in consumption improve when smart meters and IHDs are combined with time-of-use prices or varying prices, but not by much – often to no more than 10%, and for reductions in peak demand, rather than overall demand. Strengers (2015) also confirmed in her survey a wide success and failure rate with trails concerning IHDs, smart meters, and time of use tariffs, reporting a reduction in consumption between 0 and 20%.

Table 5
Results from Smart Meter Studies relevant to the United Kingdom.
Source: Authors' compilation based on House of Commons Science and Technology Committee (2016); Chilvers and Longhurst (2016); Viitanen et al. (2015), Notes: DECC = Department of Energy and Climate Change. Ofgem = Office of Gas and Electricity Markets. ToU – Time of Use *POST = Parliamentary Office of Science and Technology. EDF = Electricity de France. SSE = Southern and Scottish Energy.*

Location	Period	Name	Sponsor	Scale	Demand reduction	Notes
a. Top panel: studies with in-home displays						
United Kingdom	2007–2010	Energy Demand Research Project	Ofgem	18,370 households with smart meters, four suppliers	Around 3%, but with some higher or lower savings, depending on fuel, customer group and period	Commissioned from AECOM by Ofgem on behalf of DECC
Netherlands	2014	Netherlands trials	Rijskdienst voor Ondernemend Nederland	670 households (with a control group of 50,000 households)	0.9% (gas), reductions for electricity not statistically significant	Smart metering did not include an in-home display
United Kingdom	2015	Early Learning Project	DECC	Analysis of consumption data for 10,000 households	2.3% (electricity), 1.5% (gas), although "it is realistic to expect durable energy savings of 3% based on evidence from the research literature and trials worldwide, the ELP findings and the potential improvements identified".	Research conducted for DECC by the Environmental Change Institute, University of Oxford, the University of Ulster, and the Tavistock Institute
Ireland	2009–2010	CER Smart Meter Trials	Commission for Energy Regulation	5028 households	2.5% (electricity)	Used a combination of Time of Use tariffs and demand side reduction
United Kingdom	2014	British Gas	POST	40,000 gas smart meters and 60,000 electricity smart meters	3% (electricity and gas)	Information provided via post from British Gas for their Evidence Check
United Kingdom	2015	Opower	University of Manchester	Two residential developments in Leeds and Sheffield	1.5–2.5% (electricity)	Measured "consistent steady-state saving" over 33 months
b. Bottom panel: studies with time-of-use tariffs						
United Kingdom	2007–2010	Energy Demand Research Project	EDF, SSE	Approximately 1500 households	Up to 10% of peak load	Two ToU trials run by Offgem; one run by EDF, the other by SSE
United Kingdom	2010–2014	Consumer Network Revolution Project	Durham University, Newcastle University, Northern Powergrid	628 participants	8% reduction in average peak power demand; 6% reduction in average annual consumption during peak periods	No statistically significant reduction in average annual consumption compared to smart metering without ToU tariff
United Kingdom	2012–2014	Low Carbon London trials	UK Power Networks	1119 households	9% (peak)	Included dynamic ToU and an assessment of wind energy
United Kingdom	2014	British Gas free Saturdays or Sundays	British Gas	4000 customers	11% (peak)	Gave customers option of Dual Fuel Free Time tariffs offering free electricity every Saturday or Sunday from 9 a.m.–5 p.m
Ireland	2009–2010	Smart Meter Trials	Commission for Energy Regulation	5028 customers	8.8% in peak consumption	Study used a combination of ToU and demand side reduction
England	2008–2009	Visible Energy Trial	British Gas, Green Energy Options, SYS Consulting, and University of East Anglia	275 households	5 to 10% reduction in consumption	Three different trial types of IHDs across Eastern England plus a control group

She noted that this variance reflected many reasons that were "unclear or unspecified." Granted, even these seemingly minor to moderate reductions in individual household demand can aggregate into considerable savings, epically if they can displace or shave costly peaks in demand. But overall such savings are far less than originally expected. Moreover, the variance in savings resoundingly supports the familiar point that there is variability in how people respond to feedback, just as there is variability in how they use electricity and gas in the home (Darby, 2006).

5. Conclusion and policy implications

Based on a systematic review of academic literature and event observation regarding the UK smart meter rollout, we offer four conclusions and broader policy lessons.

First, the SMIP reveals a compelling obstacle to the vision of decentralized, prosumer based energy provision. The SMIP portrays the consumer as a rational follower of information around a single technology, rather than an emotional actor who may progressively influence what the future energy system will look like through a complex and interconnected socio-technical system. Moreover, our findings show that complexity—complexity in a liberalized market, with retailer/supplier responsibility for a rollout, with control delegated to DCCs, with complicated meter specifications and IHD requirements, and extensive consumer engagement requirements—has so far negatively shaped the UK smart meter rollout. Our findings imply that keeping an overly optimistic attitude towards consumer engagement with smart meters and in-home displays and the potential benefits for vulnerable households—at least at the events the authors participated in—seems somewhat "thoughtless", considering the critiques coming from a diverse set of actors such as academics, consumer bodies, and parliamentary committees. Furthermore, this grounding in reality, and an appreciation of challenges and failures, also serves as an antidote to recent studies framing the smart meter transition in Europe as an "imaginary" full of cooperation, hope, democracy, and sanguinity (Engels et al., 2015; Skjølsvold and Lindkvist, 2015; Vesnic-Alujevic et al., 2016). Creating meaningful feedback mechanisms to engage consumers requires (more) time to trial different options in diverse settings. Doing so can help overcome social barriers, perhaps increasing smart meter implementation and ultimately, long-term affectivity. Otherwise, the route to a smarter energy system will remain littered with obstacles.

Second, issues of timing, learning, and alternatives are important. Regardless of the size of eventual energy savings per household, or whether the 2020 target is met (or not), the engagement part of the SMIP should not be condemned before considering the counterfactual in which smart meters were rolled out with no thought at all for engagement. Or, another counterfactual in which the UK did not have any smart meters. Or, even another counterfactual in which smart meters were rolled out by network managers rather than by retailers, as is normal in much of the rest of the world (and would have made the rollout perhaps significantly less expensive). Given that the SMIP is an ongoing process that can still be augmented and improved, these counterfactuals are worth considering. The earlier phases of the SMIP also deserve credit for putting an unusual amount of effort and attention into trials coupled with a genuine commitment and willingness to learn on the part of both government and industry.

Third, the SMIP can do better. Although one can question the efficacy of a government mandated rollout passed to energy providers and suppliers at this stage, it remains likely that fairly little can be altered at this point. Nonetheless, for the smart meters and IHDs to more meaningfully empower consumers in the UK, the SMIP must grapple more explicitly with issues of vulnerability and resistance. A number of policy and business recommendations thus emerge from our material, summarized by Table 6.

For smart meter suppliers, businesses, and the DCC, the ideology behind the SMIP needs to expand from an existing platform focused on information and competition to one also incorporating justice and equity. Mechanisms need put in place to ensure that *all* consumers benefit. This includes adopting a more realistic sense of how consumers behave, not only around the SMIP and Smart Energy GB narratives of "enabling" or "empowering" so often seen in its advertisements and discussed at events, but encompassing other factors such as sabotage, defiance, anger, mistrust, and concerns over privacy. Furthermore, businesses, suppliers, and the DCC need to continue to strengthen relationships with local authorities, housing associations, charities, landlords, community leaders and other stakeholders, who can all become points of contact offering the customer more familiar surroundings and help dilute feelings of mistrust, resistance, or ambivalence. Lastly, businesses, suppliers, and the DCC need to better account for, and manage, potential vulnerabilities and as well as produce a broader range of outreach and communication materials that are easier to understand, especially among the elderly or the extremely poor, efforts that can still be improved (Citizens Advice, 2017). Recent partnerships between the Citizens Advice and Smart Energy GB (Smart Energy GB, 2016) as well as the Center for Sustainable Energy and Scottish & Southern Energy (SSE) (Hodges, 2017) are an encouraging sign that such concerns are beginning to be addressed.

In terms of recommendations for government, BEIS, Ofgem, and others such as the Committee on Climate Change should revisit and update projections of SMIP costs and benefits, given advances in

Table 6
Summary of Recommendations for the Smart Meter Implementation Program in the United Kingdom.
Source: Authors. Note: SMIP = Smart Meter Implementation Program. IHD = in-home display. Ofgem = Office of Gas and Electricity Markets. BEIS = Department for Business, Energy & Industrial Strategy. DCC = Data Communications Company. WEEE = Waste Electrical and Electronic Equipment

Stakeholders	Recommendation
Electricity and gas suppliers, DCC, Smart Energy GB	Continue to enhance engagement with customers early and apply an understanding of their specific needs
	Recognize not only narratives of enablement and empowerment but those of sabotage, defiance, anger, mistrust, and concerns over privacy
	Strengthen relationships with local authorities, housing associations, charities, landlords, community leaders and other stakeholders
BEIS, Ofgem, Committee on Climate Change	Revisit and update projections of SMIP costs and benefits
	Better assess and account for issues of equity in how SMIP benefits and burdens are distributed, especially among vulnerable groups
	Assess how smart meters connect with and can benefit prosumers and prosumption
	Consider how consumer empowerment connects to and can be supported by other policy instruments, e.g. fuel poverty, low energy homes and retrofits.
	Account for embodied emissions and lifecycle externalities and add smart meters and IHDs to the WEEE Regulations, or domestic equivalent
	Conduct more refined lifecycle analyses to determine the range and sensitivities of energy payback ratios and energy return on investment for various smart meter configurations
	Consider extending or relaxing the 2020 target for universal adoption by every household

technology as well as new data suggesting that households will reduce their energy consumption far less than anticipated – by an average of 1–3% rather than the previously proclaimed and projected 5–15%. BEIS and Ofgem should also assess issues of equity in how such benefits and burdens are distributed, especially among vulnerable groups. The government should consider how other policy instruments aimed to reduce and balance energy demand, such as those directed at fuel poverty, low-energy homes, and retrofitting, connects with and improves customer empowerment. Moreover, to account for some of the embodied emissions and externalities associated with smart meters and IHDs, those devices could be added to the Waste Electrical and Electronic Equipment (WEEE) Regulations concerning recycling, updated most recently in 2013, or a domestic equivalent if the UK decides to abandon this directive from the European Union. More refined lifecycle assessments should be conducted to determine the range and sensitivities of energy payback ratios and energy return on investment for different smart meter configurations in the UK. Lastly, the government as a whole may also need to rethink the rigidity of the 2020 target for universal diffusion.

Fourth, and critically, the SMIP reflects the contested politics of the smart economy. The SMIP represents not only an attempt to change or revolutionize energy demand, it reflects the different competing interests, or groups of interests, involved in achieving that goal. The SMIP symbolizes a radical change to how incumbents must manage the electricity system; a site of contestation over whether electricity provision ought to be a public service or private commodity; a clash of visions over centralized or decentralized supply; at times consumer understanding, awareness and empowerment pitted against the competitive needs of industry. Yet, simultaneously, its implementation follows the logic of the existing centralized energy system, placing large suppliers as the main actors in the rollout and having centrally steered processes that pay rather little attention to the margins. The SMIP also provides an example of where policy has outpaced technology, with ambitious, exuberant targets that had to be repeatedly scaled down in the face of mounting technical challenges.

Ultimately, planners may have thought that the SMIP was a fairly simple intermediation between electricity supply and consumption. Instead, they find themselves opposed on both sides. As Darby (2010) has noted, the rollout of smart meters is a multi-scalar process, one that requires transition and change among multiple levels of the system simultaneously – macro changes at the level of electricity and gas networks and decarbonization; meso level changes in consumer relations, the DCC, DNOs, and suppliers; and local or micro level changes in household decisions over appliances, IHDs, feedback, lifestyles and social practices. Some industry and government players—especially government departments stuffed full of economists and engineers—may see a smart grid as mostly an intelligently connected set of wires and technologies. Instead, they need to broaden their conception.

The ability to reconfigure all of these elements of the sociotechnical system at once belies the promise of the smart economy, but also the peril. UK planners should be lauded for their visionary, ambitious attempt to decarbonize homes and buildings with the world's largest smart meter program with the aid of consumers; but that almost hubristic agenda needs matching with equal intensity paid to implementation and recognition of what it will take to truly empower consumers.

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References

[BEIS] Business Energy & Industrial Strategy and [Ofgem] Office of Gas and Electricity Markets, 2013. Smart meters: information for industry and other stakeholders. January 22, available at ⟨https://www.gov.uk/guidance/smart-meters-information-for-industry-and-other-stakeholders⟩.

Blowers, A., Leroy, P., 1994. Power, politics and environmental inequality: a theoretical and empirical analysis of the process of ‘peripheralisation’. Environ. Politics 3 (2), 197–228, (Summer).

[DECC] Department of Energy and Climate Change, 2013. Smart Metering Implementation Programme. Department for Energy and Climate Change, London.

[DECC] Department of Energy and Climate Change, 2015a. Smart Metering Implementation Programme: DECC's policy conclusions - Early Learning Project and Small-scale Behaviour Trials. Department of Energy and Climate Change, London, available at⟨https://www.gov.uk/government/publications/smart-metering-early-learning-project-and-small-scale-behaviour-trials⟩.

[DECC] Department of Energy and Climate Change, 2015b. Smart Metering Early Learning Project: synthesis report. Department of Energy and Climate Change), London, available at⟨https://www.gov.uk/government/publications/smart-metering-early-learning-project-and-small-scale-behaviour-trials⟩.

[DECC] Department of Energy and Climate Change, 2013c. Smart metering Implementation Programme: *Overview*. Department for Energy and Climate Change, London.

[DECC] Department of Energy and Climate Change. 2014. Smart meter roll-out for the domestic and small and medium non-domestic sectors (GB): Impact assessment (January 2014).

Al-Wakeel, Ali, et al., 2016. State estimation of medium voltage distribution networks using smart meter measurements. Appl. Energy 184, 207–218.

Balta-Ozkan, Nazmiye, Amerighi, Oscar, Boteler, Benjamin, 2014. A comparison of consumer perceptions towards smart homes in the UK, Germany and Italy: reflections for policy and future research. Technol. Anal. Strateg. Manag. 26 (10), 1176–1195.

Barnett, Michael, 2015. The £100m campaign you've never heard of. Marketing Week, August 6, available at ⟨https://www.marketingweek.com/2015/08/06/the-100m-campaign-youve-never-heard-of/⟩.

Barnicoat, Greta, Danson, Mike, 2015. The ageing population and smart metering: a field study of householders' attitudes and behaviours towards energy use in Scotland. Energy Res. Soc. Sci. 9 (2015), 107–115.

Bellantuono, Giuseppe, 2014. Comparing Smart Grid Policies in the USA and EU. Law Innov. Technol. 6 (2), 221–264.

Bradley, P., Fudge, S., Leach, M., 2016. Motivating energy conservation in organisations: smart metering and the emergence and diffusion of social norms. Technol. Anal. Strateg. Manag. 28 (4), 435–461.

Brignal, Miles, 2016. Smart meters: an energy-saving revolution or just plain dumb? Guardian⟨https://www.theguardian.com/money/2016/oct/01/smart-meter-energy-saving-revolution-cut-bills-gas-electricity⟩.

Buchanan, K., et al., 2015. The question of energy reduction: the problem(s) with feedback. Energy Policy 77, 89–96.

Buchanan, K., et al., 2016. The British public's perception of the UK smart metering initiative: threats and opportunities. Energy Policy 91 (2016), 87–97.

Chilvers, Jason, Longhurst, Noel, 2016. Participation in transition(s): reconceiving public engagements in energy transitions as co-produced, emergent and diverse. J. Environ. Policy Plan. 18 (5), 585–607.

Citizens Advice, 2017. Smart support: Support for vulnerable consumers in the smart meter roll-out. (March).

Clark, Pileta, 2016. MPs warned of sabotage threat from smart meter hackers. Financ. Times⟨https://www.ft.com/content/325f66b8-8177-11e6-bc52-0c7211ef3198?mhq5j=e2⟩.

Committee on Climate Change, 2016a. Meeting carbon budgets – 2016 progress report to parliament. Retrieved from ⟨https://www.theccc.org.uk/publication/meeting-carbon-budgets-2016-progress-report-to-parliament⟩.

Committee on Climate Change, 2016b. Fifth carbon budget dataset. July 6, available at ⟨https://www.theccc.org.uk/publication/fifth-carbon-budget-dataset/⟩.

Darby, S., 2006. The Effectiveness of Feedback on Energy Consumption—a Review for DEFRA of the Literature on Metering, Billing and Direct Displays. Environmental Change Institute, Oxford University⟨http://www.eci.ox.ac.uk/research/energy/downloads/smart-metering-report.pdf⟩.

Darby, S., 2009. Implementing article 13 of the energy services directive and defining the purpose of new metering infrastructures. In: Proceedings of the European Council

for an Energy-Efficient Economy Summer Study. Paper (2262).
Darby, Sarah, 2008. Energy feedback in buildings: improving the infrastructure for demand reduction. Build. Res. Inf. 36 (5), 499–508.
Darby, Sarah, 2010. Smart metering: what potential for householder engagement? Build. Res. Inf. 38 (5), 442–457.
Engels, Franziska, Münch, Anna Verena, 2015. The micro smart grid as a materialised imaginary within the German energy transition. Energy Res. Social. Sci. 9, 35–42.
European Commission. 2017. Smart metering deployment in the European Union (Joint Research Centre: available at ⟨http://ses.jrc.ec.europa.eu/smart-metering-deployment-european-union⟩.
Gosden, Emily, 2015a. Energy smart meter roll-out may be 'costly failure', MPs warn. Telegraph, available a)⟨http://www.telegraph.co.uk/news/earth/energy/11456193/Energy-smart-meter-roll-out-may-be-costly-failure-MPs-warn.html⟩.
Gosden, Emily, 2015b. One in 10 energy smart meters doesn't work. Telegraph, available at⟨http://www.telegraph.co.uk/news/earth/energy/11857093/One-in-10-energy-smart-meters-doesnt-work.html⟩.
Groves, Christopher, Henwood, Karen, Shirani, Fiona, Butler, Catherine, Parkhill, Karen, Pidgeon, Nick, 2016. The grit in the oyster: using energy biographies to question socio-technical imaginaries of 'smartness'. J. Responsible Innov. 3 (1), 4–25.
Hamilton, Ian G., Alex, J. Summerfield, Lowe, Robert, Ruyssevelt, Paul, Elwell, Clifford A., Oreszczyn, Tadj, 2013. Energy epidemiology: a new approach to end-use energy demand research. Build. Res. Inf. 41 (4), 482–497.
Hess, David J., 2014. Smart meters and public acceptance: comparative analysis and governance implications. Health, Risk Soc. 16 (3), 243–258.
Hodges, Nicky. 2017. Supporting Vulnerable Households to Benefit from Smart Meters: Making Smart Energy Data Accessible to all. Centre for Sustainable Energy. January. Available at ⟨https://www.cse.org.uk/projects/view/1319⟩.
House of Commons Science and Technology Committee, 2016. Evidence check: smart metering of electricity and gas, September 24.
Jenkins, Nick, Long, Chao, Wu, Jianzhong, 2015. An overview of the smart grid in Great Britain. Engineering 1 (4), 413–421.
Kahma, Nina, Matschoss, Kaisa, 2017. The rejection of innovations? Rethinking technology diffusion and the non-use of smart energy services in Finland. Energy Res. Soc. Sci. 34, 27–36.
Kotter, Richard, 2013. The developing landscape of electric vehicles and smart grids: a smart future? Int. J. Environ. Stud. 70 (5), 719–732.
Lewis, Dan, Kerr, Jamie, 2014. Not Too Clever: Will Smart Meters Be the Next Government IT Disaster?. Institute of Directors, London.
Liddell, Christine, 2015. Human factors in energy efficient housing: insights from a Northern Ireland pocket neighbourhood. Energy Res. Soc. Sci. 10, 19–25.
Louis, Jean-Nicolas, Calo, Antonio, Leiviskä, Kauko, Pongrácz, Eva, 2015. Environmental impacts and benefits of smart home automation: life cycle assessment of home energy management system. IFAC-Pap. 48 (1), 880–885.
MacDonald, Mott, 2007. Appraisal of costs & benefits of smart meter roll out options. (Brighton: Final Report, April).
Marres, N., 2012. Material Participation: Technology, the Environment and Everyday Publics. Palgrave, London.
Martiskainen, Mari, Coburn, Josie, 2011. The role of information and communication technologies (ICTs) in household energy consumption—prospects for the UK. Energy Effic. 2011 (4), 209–221.
Marvin, S., Chappells, H., Guy, S., 1999. Pathways of smart metering development: shaping environmental innovation. Comput. Environ. Urban Syst. 23, 109–126.
Meadows, Sam, Brodbeck, Sam, 2017. Smart meter roll-out: is getting one still compulsory? Telegraph, available at⟨http://www.telegraph.co.uk/bills-and-utilities/gas-electric/smart-meter-roll-out-getting-one-still-compulsory/⟩.
Murphy, Margi, 2016. Smart meters: a timeline of the UK rollout - energy customers are cynical about the rollout. Comput. World, (available at)⟨http://www.computerworlduk.com/galleries/it-management/energy-customers-are-cynical-about-rollout-click-through-its-history-3592762/⟩.
Murphy, Maria Helen, 2016. Technological solutions to privacy questions: what is the role of law? Inf. Commun. Technol. Law 25 (1), 4–31.
National Audit OfficePreparations for the roll-out of smart meters, HC 1091, session 2010-2012, 30 June 2011, London. Available at http://www.nao.org.uk/idoc.ashx?DocId=6854152F-711C-4B5A-AB79-C829BA80A504 & version=−1.
National Audit Office. 2014. Update on preparations for smart metering. Available at ⟨https://www.nao.org.uk/report/update-on-preparations-for-smart-metering/⟩.
Ofcom, 2016. Communications market report: Scotland. August 4. Available at ⟨https://www.ofcom.org.uk/__data/assets/pdf_file/0024/43476/CMR_Scotland_2016.pdf⟩.
Ofgem, 2010. Smart metering implementation programme: data privacy and security. July 27. Available at ⟨https://www.ofgem.gov.uk/ofgem-publications/63546/smart-metering-data-privacy-and-security.pdf⟩.
Ofgem. 2004. Ofgem's current work on consumer information paper for the environmental advisory group. Available at ⟨https://www.ofgem.gov.uk/ofgem-publications/57991/9070-eaconsumerinformation.pdf⟩.
Ofgem. 2016. British Gas Business to pay £4.5 million for failing to meet advanced meter deadline. December 7. Available at ⟨https://www.ofgem.gov.uk/publications-and-updates/british-gas-business-pay-4-5-million-failing-meet-advanced-meter-deadline⟩.
Orlowski, A., Ray, B., 2012. Smart meters won't be compulsory. Register, available at) ⟨https://www.theregister.co.uk/2012/02/01/smart_meters_yesno/⟩.
Palmer, Kate, 2015a. Billing glitches for first customers of £11bn smart meter roll-outThe Telegraph, available at⟨http://www.telegraph.co.uk/finance/personalfinance/energy-bills/11622798/Billing-glitches-for-first-customers-of-11bn-smart-meter-roll-out.html⟩.
Palmer, Kate, 2015b. 1.5 million smart meters won't work when you switch energy supplier. Telegraph, available at)⟨http://www.telegraph.co.uk/finance/personalfinance/energy-bills/11643750/1.5-million-smart-meters-wont-work-when-you-switch-energy-supplier.html⟩.
Petticrew, M., Roberts, H., 2006. Systematic Reviews in the Social Sciences: a Practical Guide. Wiley-Blackwell, Malden, MA.
Poghosyan, Anush, et al., 2015. Long term individual load forecast under different electrical vehicles uptake scenarios. Appl. Energy 157, (699–70).
Public Accounts Committee, 2012. Preparation for the Roll-out of Smart Meters, Sixty-third Report of Session 2010-12, HC637 17. The Stationery Office, London, available at⟨http://www.publications.parliament.uk/pa/cm201012/cmselect/cmpubacc/1617/1617.pdf⟩.
Pullinger, M., Lovell, Heather, Webb, Janette, 2014. Influencing household energy practices: a critical review of UK smart metering standards and commercial feedback devices. Technol. Anal. Strateg. Manag. 26 (10), 1144–1162.
Robinson, A.P., Blythe, P.T., Bell, M.C., Hübner, Y., Hill, G.A., 2013. Analysis of electric vehicle driver recharging demand profiles and subsequent impacts on the carbon content of electric vehicle trips. Energy Policy 61, 337–348.
Rose, David, Thed, Martin, 2014. Unveiled: new £200 'smart' meters every household must pay for (but may not work). Mail Sunday, available at)⟨http://www.thisismoney.co.uk/money/bills/article-2681954/Unveiled-New-200-smart-meters-household-pay-not-work.html⟩.
Savirimuthu, J., 2013. Smart meters and the information panopticon: beyond the rhetoric of compliance. Int. Rev. Law, Comput. Technol. 27 (1–2), 161–186.
Shannon, Laura, 2015. Just how smart are these energy meters? Financ. Mail Sunday, available at⟨http://www.thisismoney.co.uk/money/bills/article-3084432/ERROR-Smart-energy-meters-leave-hundreds-thousands-households-billing-limbo.html⟩.
Skjølsvold, Tomas Moe, Lindkvist, Carmel, 2015. Ambivalence, designing users and user imaginaries in the European smart grid: insights from an interdisciplinary demonstration project. Energy Res. Soc. Sci. 9, 43–50.
Smart Energy GB, 2015. Smart energy outlook. Available at ⟨http://www.smartenergygb.org/sites/default/files/Smart%20Energy%20Outlook%20March%202015%20For%20ONLINE%20Publication.pdf⟩.
Smart Energy GB. 2016. Citizens advice partners with Smart Energy GB to spread the word about smart meters. July 18, available at ⟨https://www.smartenergygb.org/en/resources/press-centre/press-releases-folder/citizens-advice-partnership⟩.
Smart Energy GB. 2017. Smart Meters – what is a Smart Meter. March 10, available at ⟨https://www.smartenergygb.org/en/resources⟩.
Sorrell, Steve, 2007. Improving the evidence base for energy policy: the role of systematic reviews. Energy Policy 35, 1858–1871.
Sovacool, B.K., 2016. How long will it take? Conceptualizing the temporal dynamics of energy transitions. Energy Res. Soc. Sci. 13, 202–215.
Staffell, Iain, 2017. Measuring the progress and impacts of decarbonising British electricity. Energy Policy 102 (2017), 463–475.
Strengers, Yolande, 2015. Negotiating everyday life: the role of energy and water consumption feedback. J. Consum. Cult. 11 (3), 319–338, (2011).
Thomas, Stephen, 2012. Not too smart an innovation: UK plans to switch consumers to smart gas and electricity meters. Energy Environ. 23 (6/7), 1057–1074.
Utility Week. 2017. Smart metering: challenging times lead to strange bedfellows, May 10, 2017, available at ⟨http://utilityweek.co.uk/news/smart-metering-challenging-times-lead-to-strange-bedfellows/1302322#.WU_6OWjyvIV⟩.
Vallés, Mercedes, et al., 2016. Regulatory and market barriers to the realization of demand response in electricity distribution networks: a European perspective. Electr. Power Syst. Res. 140, 689–698.
Vesnic-Alujevic, Lucia, Breitegger, Melina, Pereira, Ângela Guimarães, 2016. What smart grids tell about innovation narratives in the European Union: hopes, imaginaries and policy. Energy Res. Soc. Sci. 12, 16–26.
Viitanen, Jenni, Connell, Paul, Tommis, Martine, 2015. Creating Smart Neighborhoods: Insights from Two Low-Carbon Communities in Sheffield and Leeds, United Kingdom. J. Urban Technology 22 (2), 19–41.
Yin, Robert K., 2003. Case Study Research: Design and Methods. Sage, London.
Zhang, Tao, Nuttall, William J., 2011. Evaluating government's policies on promoting smart metering diffusion in retail electricity markets via agent-based simulation. J. Product. Innov. Manag. 28, 169–186.