Review

Customer Privacy Concerns as a Barrier to Sharing Data about Energy Use in Smart Local Energy Systems: A Rapid Realist Review

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Table S1. Abbreviations

EnergyREV	The EnergyREV (Energy Revolution) consortium has been formed to help drive forward research and innovation in smart local energy systems. EnergyREV is one of the three key components of the UK Industrial Strategy Challenge Fund's Prospering from the Energy Revolution (PFER) programme.
EPPI-Centre	Evidence for Policy and Practice Information Coordinating Centre. A research centre specializing in systematic reviews for policy and practice. Based in the Institute for Social Research, UCL.
GDPR	General Data Protection Regulation. The European Union data protection regulations that came into force (2018). All entities that process personal data must comply with seven accountability and transparency principles: (1) lawfulness, fairness, and transparency; (2) purpose limitation; (3) data

	minimization; (4) accuracy; (5) storage limitation; (6) integrity and confidentiality; (7). accountability.
PFER	Prrospering from the energy revolution. An investment by the UK government's Industrial Strategy Challenge Fund (ISCF).
SLES	Smart Local Energy Systems. Future energy systems characterised by decentralized energy, requiring detailed customer energy use data to understand system performance in increasingly finer detail for grid balancing.

Table S2. Search terms for energy sharing data studies in bibliographic databases

1. Terms for Privacy	2. Near Terms for Data	3. Terms of Data Sharing and Privacy Behaviours
Privacy	Data	Behavior
Private	Information	attitude
personal		Calculus
sensitive		concern
secure		"tradeoff"
security		trade-off

Anony*

confidential

intimate

safety

Data privacy

Intention

preserv*

issue*

Anxiet*

Incentiv*

"risk perception"

Caution

Paradox

Trust

Barrier

Percept*

Perceived

"data sharing"

"willingness to disclose"

Table S3. Hypothesised contexts, mechanisms and outcomes for Guiding principle 1.

Context	**Mechanism**	**Outcomes**
Individual, Micro and meso system.	Communication of a complete and relevant knowledge of risks and benefits to data sharing through usable privacy notices. Knowledge increases, and there is greater understanding and desire for benefits of sharing data	Active and sustained participation of customers in sharing data and involvement in active energy use behaviours
Meso system	Recognition and communication of interdependence and mutual benefit. Partnership working with community groups, individuals, and business.	Customer achieve their benefits and SLES System achieves balance and resilience through real time data collection and responsive energy use behaviours of customers'
Meso to micro	Resource. Outreach: Active and ongoing support, education and training	Inclusion of all customers, including those that may be at risk of exclusion.

Guiding principle 1. Recognize the mutual benefits of data sharing for smart local energy systems and work with customers as partners.

Table S4. Hypothesised contexts, mechanisms and outcomes for Guiding principle 2.

Context	Mechanism	Outcomes
Individual; and Micro system	Individual sense of autonomy, choice and control, self-efficacy, locus of control.	Active or passive resistance or active and continued use
	Active involvement in the design increases sense of control	Trusted devices and technologies are adopted and used
	Tailoring of technologies or service to meet personal goals: whether saving money, or "going green"	Devices and technologies perceived to be compatible with personal values are adopted and used
Meso system	Ease of integration, into existing technologies and ways of living.	Devices and technologies perceived to be useful are adopted and used

Guiding principle 2. Involve people in the design of data sharing technologies from the start.

Table S5. Hypothesised contexts, mechanisms and outcomes for Guiding principle 3.

Context	Mechanism	Outcomes
Micro through to meso systems	Existing familiarity of privacy choices and controls. Usable privacy is accessible and relevant	Sharing or not sharing data can depend on existing knowledge, and how similar or different the privacy notices are compared to what people have already experienced.
Micro systems	Having a choice over which third parties to share data with creates trust	Blocking sharing data can be a default position, where the third parties are unknown

Guiding principle 3. Give people a say on the third parties that they are happy to share data with

Table S6. Hypothesised contexts, mechanisms and outcomes for Guiding principle 4

Context	Mechanism	Outcomes
Individual and Micro through to macro	Privacy is relational and contextual. Control over information settings should allow for the setting of boundaries around what is acceptable or not acceptable for each context and time.	Empowerment over the control flow of information.

Guiding principle 4. Empower people to set the boundaries around the flow of information about themselves

Table S7. Hypothesised contexts, mechanisms and outcomes for Guiding principle 5

Context	Mechanism	Outcomes
Micro to meso	Ambivalence that people will see any real benefit to themselves	Lack of trust in the extent and purpose of data collection inhibits take up
Micro system	Anticipating benefits or Unanticipated consequences of being "flexible"	Resistance or disappointment to unanticipated perceived intrusions into daily life
Micro system	Understanding and knowledge of privacy conditions	Withdrawal of consent as a default safety mechanism

Guiding principle 5. Ensure that the purpose and value of the data collected is transparent and fair

Table S8. Hypothesised contexts, mechanisms and outcomes for Guiding principle 6

Context	Mechanism	Outcomes
Meso system	Resource: Methods of accounting and billing allows for multiple account holders.	People who affected by energy use monitoring give their informed consent to the extent and depth of energy data collection.
Individual, Micro and Meso system	Values and beliefs of the household, differing priorities of members of the household., assumptions made about the use of monitoring technology.	Over-monitoring, energy use data used as a vector of control
	Assumptions of service providers about capacity of customers to receive and understand information about technology and services.	Including or excluding groups of people from decision making around the benefits of data sharing, including financial benefits and efficiencies, or other "off label" benefits.

	Resource: active outreach for education, demonstration and training	
Meso and macro systems	Principle -gent problem over investment and benefit. Resource: Incentives for investments and ongoing support	People affected by data sharing are excluded from decision making leading to passive resistance and use of technology is not sustained. SLES access to data is limited and declines over time.

Guiding principle 6. Ensure that everyone that is affected by sharing of data is involved in giving their informed consent.

Table S9. Hypothesised contexts, mechanisms and outcomes for Guiding principle 7.

Context	**Mechanism**	**Outcomes**
Micro and meso systems	Balance of power in a household. The visibility revealed by the use of energy monitoring data can shift this balance. Peer pressure to monitor behaviors Resource: Methods of accounting and billing allows for multiple account holders and permissions to change granularity of data granted to those on the account	Over monitoring, energy use data used as a vector of control. Multiple account holders should reduce the potential for the use of energy data to be used for gaslighting, or coercive control
Meso and macro systems	Ethical design principles Innovative use of detailed energy use data by household may generate unintended consequences	Minimise the impact of unintended consequences

Guiding principle 7. Recognize that technologies for revealing and monitoring behaviours in the home can be used in unexpected and unwanted ways.

Table S10. Hypothesised contexts, mechanisms and outcomes for Guiding principle 8.

Context	Mechanism	Outcomes
From micro to macro systems	Open channels of communication	Swiftly address the impact of unintended consequences
	Resources: outreach for stakeholder identification and involvement to include different perspectives into ethical design principles	Establish an ongoing process of evaluation

Guiding principle 8. Ensure there are channels of feedback and ongoing communication to continuously improve service delivery.

Table S11. Data sharing technologies and systems in each domain.

Data sharing technologies in the individual domain	These are usually operated by one person at a time, or one person has sole responsibility, they are usually password protection. Smart devices, Electric vehicles, personal computers, Apps.
Data sharing technologies in the Micro domain	These are technologies that are in the home. Users interact with sensors, Internet of things, Home networks, smart meters, smart appliances, smart home
Data sharing technologies in the Meso domain	These are technologies related to the local energy system and community based services. EV charging, Smart grid, Data storage servers, Smart local energy systems, Community based energy.
Data sharing technologies in the macro domain	These technologies at this level tend to be outside of the individual control and influence. This includes, internet, Cellular communications., powerline communications. Data protection policies, cloud storage.

Type of data sharing technologies in each domain.

Table S12. Study characteristics and quality appraisal for included primary studies

Short Title	**Country**	**Type of study**	**Number of participants**	**Type of intervention**	**Components of intervention**	**Aim of intervention**	**Users of data**
S1. Bailey (2015) ++/++	Canada	**Observational** • Survey	1470 CPEVS survey. n = 530 in discrete choice experiments	Smart charging of PEVs	• Alternative energy source • Budget information	To allow load management, reduce system costs, subsidize PEV market, increase use of renewables	• Energy provider
S2. Begier (2014) -/++	Poland	**Observational** • Interviews • Survey	4 focus groups, 302 interview participants total: 963 persons)	Smart meters	• Communication • Email information • Home computer • In home displays • Information • Internet access • Personal visit by representative • Variable rates	Main technical purposes of smart metering, like energy saving, reducing total energy consumption, especially reducing peak demand of energy	• Criminals • Energy provider
S3. BEIS (2018) +/++	Great Britain	**Review** • Audit	NA	Regulation Regulatory framework	• Communication • Smart meter smart metering Data Access and Privacy Framework.	The Framework establishes sector-specific provisions relating to the processing of energy consumption data, which are designed to complement, but not replace, wider data protection legislation [e.g. GDPR)	• Consumers • Energy network operator • Energy provider • Third party organizations
S4. Choe (2012) +/+	USA	**Observational** • Activity diary • Interviews	11 couple households	In Home sensors	• Diary • Home computer • Sensor lights • Technology education session	Sensors can help make decisions about energy efficiency.	

S5. Citizens Advice Bureau (2019) ++/++	Great Britain	**Observational** • Survey • process evaluation	• 3008 online interviews • 213 face to face interviews.	• Smart appliances • Smart meters	• Smart meter	Smart meters and smart devices aim in part to facilitate a more flexible electricity system	• Corporations • Energy provider
S6. Da Silva (2012) -/++	Multiple locations	**Observational** • Survey	• Not clear end prosumers of electricity in the residential sector	• Demand Side Response • Small scale renewable energy provision Prosumers • Smart grid	• Real time information	Smart grids provide services for prosumers (e.g. comparing usage to similar local households), based on information provided by the prosumers (e.g. real time consumption data).	• Energy provider "retailer"
S7. Delmas (2014) +/++	USA	**Experimental** • Quasi	66 rooms, 102 participants	Feedback Public vs. private feedback	• Email information • home energy monitoring device • In home displays • Information posters • Real time information	(To) test the efficacy of detailed private and public information on electricity conservation.	Not stated
S8. Fell (2015) +/++	Great Britain	**Observational** • Survey	2159/ 2302 people full omnibus study	Demand Side Response	• Electric heating	Demand side response (DSR) Simply defined as 'change in electricity consumption patterns in response to a signal' (Element Energy 2012, 9), DSR offers the ability to sculpt demand for electricity to fit the available supply.	Not stated
S9. Giordano (2011) +/+	Europe	**Observational** • Survey	• Not clear	Smart grid	• Authentication • Authorization • Certification • Encryption	(to).. foster greater consumption awareness taking advantage of Smart Metering systems and improved customer information, in order to allow consumers to	• Criminals • Market analysts • Insurance companies

					• Ensures integrity and confidentiality	modify their behavior according to price and load signals and related information.	
S10. Guerreiro (2015) -/+	Portugal	**Observational** • Survey • Discourse analysis of blogs	515 residents in the city of Évora	Smart meters	Not stated	Smart meters permit smart grids, including by giving people feedback on their energy use so they can alter consumption patterns	• Energy provider
S11. Hansen (2017) +/+	Denmark	**Observational** • Case study	20 households	Smart grid	• Electric vehicles n = 17 • Geothermal Heat pump Hybrid air/ water HP with gas, air/water HP, • home energy monitoring device • Internet access • Photovoltaics PVs • Real time information • Sensors • Smart meter • Sun Wells	the.. main idea of Insero Live Lab was to test the remote control of electricity-consuming devices (EVs and HPs) combined with electricity-producing devices, PVs.	• Consumers • Energy provider
S12. Hess (2014) +/++	• Canada • USA:	**Observational** • Case study	75 organizations or information sites that gave reasons for opposing smart meters	Smart meters	Not stated	Smart meters can help achieve "more resilient and sustainable electricity consumption"	Not stated
S13. Hmielowski (2019) ++/++	USA	**Observational** • Survey	1035	Smart meters	• Information Description and picture of smart meter (and mechanical meter).	To support/inform the installation of smart meters to increase energy efficiency, reduce costs and greenhouse gases.	• Energy provider

S14. Hoenkamp (2012) +/+	The Netherlands	**Observational** • Case study	• National	Smart meters	• Compulsory roll out • In home displays • Real time information • Smart meter	Smart … play a crucial role in reaching the energy efficiency goals of the 20-20-20 targets of the EU Climate and Energy Package	Not stated
S15. Horne (2015) +/-	USA	**Observational** • Survey	Study 1 (S1) 353 Study 2 (S2) 355	Smart meters	• Real time information • Smart meter	Smart Meters contribute to the technical capacity of utility companies to manage demand (through demand response programs), incorporate renewable sources of electricity into the system, and increase the overall efficiency and reliability of the system	• Energy provider • Third party organizations
S16. Huang (2016) ++/+	Not stated	**Model** • Mixed strategy Nash Equilibrium game	NA	Incentives	• Alternative energy source PV • Battery • Smart meter	. the goal of our price-based incentive approach is to allow both parties, namely consumers and the electricity provider, to negotiate consumption and data sharing such that all parties can potentially profit from interactions.	• Energy provider
S17. Jakobi (2017) +/+	Germany	**Observational** • Focus group • Interviews	63	Smart thermostats	• An App • Dashboard • Diary home log book • Feedback • Information • Internet access • remote controls • Sensors • Smart meter • Smart plugs • Smartphone • Web Portal • Z wave	Products mainly address issues of security, energy savings and comfort. Monitoring and saving energy by avoiding standby consumption, automated switching off of devices and appliance-based measurement of energy consumption as well as visualization of consumption.	Not stated

S18. Jakobi (2019) +/++	Germany	**Observational** ethnographic case study	survey: 34/200 App: 205	Smart meters	• An App for Android • Customer choice of level of disclosure • Information • Internet access • Smart meter	(smart) meters are designed to collect information on power consumption and send it to third parties.	• Advertisers • Consumers • Third party organizations
S19. Kapade (2017) +/+	Not stated	**Model** • Game theory	1000 modelled households.	Incentives	• Area networks • Smart meter	To incentivize consumers via a credit-based system to share power consumption data that is beneficial to industries.	• Data Collectors • Third party organizations • Unethical individuals
S20. Melville (2017) -/++	United Kingdom	**Observational** • Focus group • Interviews	1st interview (prior to installation): 12 respondents. 2nd interview (after intervention period): 7 of these 12 respondents. Subsequent focus group: 5 of these 7 respondents.	Community demand response (DR)	• Consumption data • Feedback • Incentives	To influence individual consumption behavior through community accountability, (not just price signals), in an electricity demand response scheme.	• Peers
S21. Moere (2011) -/+	Australia	**Experimental** Quasi experimental study	• Intervention 6 • Control 5	Smart meters	• Feedback • Internet access • Outside home display • Sensors • Wireless network	Providing comparative feedback may have a positive effect on behavior change by triggering feelings of competition, social comparison or social pressure [26].	• Consumers
S22. Naus (2015)	The Netherlands	**Observational** • Focus group • Survey	Focus Group - 12, Survey = 171	Smart grid	• Consumption • Domestic production • Energy meter	government bodies at different levels have formulated targets to promote a transition to a low-carbon economy. households are ∗increasingly positioned as	• Energy provider

++/++					• Real time information • Variable rates	active participants with a responsibility to act as 'change agents'	
S23. Ofgem Year 9 (2018) +/++	Great Britain	**Observational** • Deliberative workshops	62 in four groups	Half-hourly settlement	Smart meter	Half-hourly settlement uses more fine-grained electricity consumption data from smart meters. It could allow more innovative energy products to be commercialized.]	• Energy provider • Government agencies
S24. Pournaras (2016) +/+	• Germany - Smart phone evaluation • Ireland - Smart Grid evaluation	**Model** • a supply-demand system	data on 6000 participants	• Incentives • Smart grid	• Authorization • Budget information • Customer choice of level of disclosure • granularity of data collection • rewards • Software tools	a Smart Grid project that studies the impact on electricity consumption of residential and enterprise consumers in Ireland.	
S25. Sexton (2018) -/-	England	**Observational** • Case study	5 in Energy case study interviews	Energy governance	• Consumption data	sharing, linking and re-use (secondary use) of government administrative data	• Government agencies • Researchers
S26. Snow (2014) ++/++	Australia	**Observational** • Interviews	S1 23 households s2 35 households	Smart meters	• Feedback • In home displays	The emerging standard of visible and sharable electricity consumption information empowers families with multiple avenues to measure, share, discuss and learn how to better manage and reduce their usage	

S27. Horne (2019) +/++	USA	**Observational** • Experimental vignette survey	S1 - 100 per condition, n = 300 S2 300 per condition, n = 1200	Smart meters	• An App	In its transition to a sustainable, reliable, efficient 'smart grid,' the system is integrating increasing amounts of ICT.	**Users of data** • App providers
S28 Toft (2015) ++/-	Denmark	**Observational** • Interviews	24 households	Smart grid	• Geothermal Heat pump	One of the key elements of the Smart Grid is that electricity consumers make some of their consumption available as flexible capacity to balance the grid. Consumers' flexible capacity is only available to the grid if the consumers adopt Smart Grid technology (SGT) that establishes the link between the electric system and the consumer.	Not stated
S29. Valor (2019) -/-	Multiple locations	**Review** "Exhaustive review"	k = 100+	Interactive feedback (via displays, apps, web portals etc.)	• An App • In home displays • Web Portal	To design domestic energy/eco feedback displays that are "more effective in creating the desired household behavioral change to maximize energy conservation."	Not stated
S30. Van Aubel (2019) ++/++	The Netherlands	**Observational** • Case study	• National	Smart meters	• Central administration • home energy monitoring device • In home displays	to discuss the how and why certain choices have been made in the Netherlands, in relation to roll out of smart meters	Not stated
S31. Vermont Trasco LLC (2014) ++/+	USA	**Observational** • Case study	Reliant 600,000 ENO 150,000 SVE 21,000 CMP 600,000	Smart grid	• Advertising • Community outreach • Critical peak rebate • Customer training • Day ahead • Email information • Incentives • In home displays	Smart Grid Investment Grant projects (aim to) modernize the electric grid, strengthen cybersecurity, improve interoperability, and collect data on smart grid and customer operations.	Not stated

					• Partnerships with local organizations • Programmable Communicating Thermostat • Phone calls • Public meetings • Smart meter • SMS Messaging • Social Media • Software tools • trained customer • Variable rates • Web Portal		
S32. Walter (2018) +/++	• Multiple locations • Germany	**Review** • Systematic **Observational** • Survey	101	Transport Connected, private cars	• event data recorder (EDR) • informative intelligent speed adaption (ISA)	Enabled by numerous connected sensors, new cars offer new functionalities, provide higher security levels and promise to enhance the comfort of travelling.	Ambulance. • App providers • Breakdown service • Car manufacturer • Family • Garage • Police • Hotels • Insurance companies • Traffic control center • Third party organizations
S33.Winter (2015) +/+	USA	**Observational** • Interviews	9	Smart meters	• Feedback • In home displays • Personalized information	Smart meters allow a utility to send commands to the meter, such as turning off the power due to nonpayment of tariffs or reducing the amount of	Corporations • Energy provider • Government agencies

					• Real time information • Smart meter • Variable rates • Wireless network	energy available to a home based on the time of day or type of energy use.	• Unethical individuals
S34. Yao (2019) ++/++	USA	**Observational** • Action research	25	Smart homes	• An App • Co-design • Hardware devices • Policy / regulation • Sensors • System modes	To create smart home designs that address users' privacy concerns.	• Car manufacturers • Third party organizations

Study characteristics of included primary studies.