Smart Future of Healthcare

Extended Executive Summary with Recommendations

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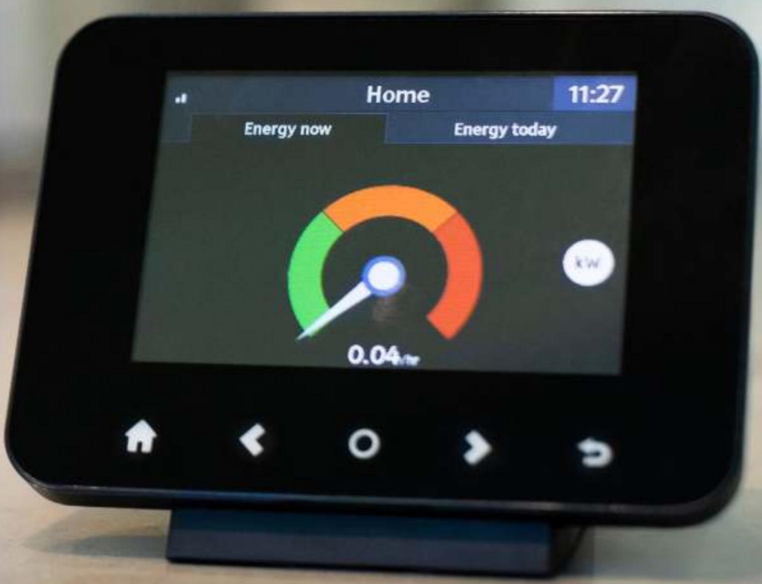

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We are currently facing the greatest set of social, health and economic challenges since the Second World War. Before January 2020, the notion of a novel virus disrupting families, communities, businesses and economies worldwide was almost inconceivable. Even more so national lockdown, where members of the public, young and old, healthy and frail, are ordered to shut themselves away inside their houses and refrain from meeting family and friends (PMO, 2020).

We began this project in September 2019, several months before the advent of COVID-19. The subject we explore is of primary relevance to these uncertain times: how to use a burgeoning communications infrastructure to remotely monitor vulnerable and frail members of society; how to recognise health deterioration as it happens and respond early; how to mobilise social capital and free up healthcare capacity; and how to keep families connected for peace of mind and wellbeing.

Great Britain's official electricity and gas smart meter roll-out programme began in 2013 and was due for completion by the end of 2020. The target was ambitious due to a range of technical and logistical obstacles, which have now been compounded by COVID-19 to delay roll-out yet further. Even so, nearly one third of energy meters in homes and small businesses (17.4 million) are now operating in smart or advanced mode with remote communication (BEIS, 2020). Within a few years, pandemic permitting, the smart meter will be the standard energy metering device in people's homes throughout the UK.

A nationwide smart meter infrastructure should enable a more agile and resilient energy system, and will put an end to billing estimations and the inconvenience of manual meter readings (BEIS/Ofgem, 2018). Smart meters can give almost real-time information on energy use and expenditure, meaning consumers can better manage their energy consumption, save money and reduce carbon emissions (Ofgem). The potential environmental benefits are indeed vital to the UK government's Clean Growth Strategy, which aims to reduce green-house gas emissions by at least 100% compared to 1990 levels (CCC, 2019).

The benefits of smart energy meters appear substantial, and recent research suggests these may extend further still.

In our Smart Future of Healthcare report, we explore a range of non-intrusive health and care monitoring solutions using smart meter data. The unique aspect of this opportunity lies in the physical hardware, the smart meter, since never

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before has there been a government-driven roll-out of communications hardware into people's homes. If used as a health and care monitoring technology, the smart meter would literally become a telehealth solution sitting in virtually every home in the UK within just a few years.

Thinking about ways to harness this technology is important because an aging society indicates a future of much greater demand on our healthcare services, which in their current form are considered unsustainable (House of Lords, 2017). Moreover, over 80% of people would prefer to stay in their own home later in life (Doyle et al., 2009). The technology may therefore bring benefits to informal carers, often family members who combine work and other family commitments with caring for a spouse or parent. In the UK, one in eight adults are carers (around 6.5 million people), and three in five people are anticipated to become carers at some point in their lives (Carers UK, 2015).

Whether or not COVID-19 remains part of our global future, the need for scalable, affordable health and care solutions is both great and urgent.

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1. Smart energy propositions and applications

Drawing from the literature, policy papers, project interviews and correspondence, we have identified three distinct remote monitoring approaches using smart meter data. These comprise (1) home monitoring for vulnerable individuals and restorative care, (2) population-level screening and monitoring, and (3) self-monitoring. Proposed approaches and service contexts are summarised in Table 1.

Table 1: Possibilities for remote health and care support using smart energy data

Monitoring	Context	Method
1. Individuals Mainly single-occupant households	Social care (formal and informal)	Monitoring of vulnerable people living alone
	Health and social care	Monitoring of long-term conditions progression
	Health care	Post-operative (rehabilitation) or post-discharge monitoring
	Health care	Impact monitoring of pharmacological or therapeutic intervention
2. Population-level Households (families/individuals) Local area (street/district)	Health and wellbeing	Screening/monitoring for fuel poverty, neglect, unhealthy living conditions Detection of any dwelling in need of fabric efficiency measures (EPC band D–G)
3. Self-monitoring Families and individuals	Health, wellbeing and safety	Monitoring for self-care and home safety

Different monitoring approaches require different methods of energy data collection and analysis, but each aims to use computerised detection methods and automated alert systems to enable early detection and intervention on a range of risks to health and wellbeing.

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1.1 Home monitoring for the vulnerable and at-risk

Research into smart energy monitoring systems for health and care purposes has proposed ways to support elderly individuals with health vulnerabilities to live safely and for longer in their own homes. The same systems could be used to support any vulnerable person living alone, such as a young person with disabilities, and also used to help monitor people post-discharge or following other medical intervention.

Most health monitoring approaches using smart energy data propose a process of non-intrusive load monitoring (NILM) to disaggregate energy consumption according to the use of electrical appliances in the home. Through machine learning, the monitoring system can recognise patterns of appliance usage over time and infer behavioural routines and activities of daily living (ADLs) of the household occupant.

Once behavioural patterns are learnt, computer algorithms are used to identify anomalous behaviour that may have relevance to health and wellbeing status. For example, unexpected inactivity may suggest incapacitation, while changes to the routine use of kitchen appliances may be an indicator of memory problems, sleeplessness, mental illness onset or disease progression (Enshaeifar et al., 2018; Lyu & Wolinsky, 2017).

Similar approaches to anomalous behaviour recognition are already used (and being further refined) in ambient assisted living (AAL) monitoring systems that use other types of sensor technologies, including smart plugs and movement sensors.[1] Upon the detection of anomalous behaviour, an alert is automatically raised and sent to a family member, care worker, telehealth hub or clinician to respond and take appropriate action.

Table 2 shows a range of potential triggers for alerts resulting from changes in energy usage patterns (implying changes in behaviours and ADLs), together with possible health implications. The particular relevance of this technology to the monitoring of long-term conditions, including Parkinson's, Alzheimer's/dementia and other neurological conditions, has been frequently noted in the literature.

1. Examples of UK providers in this space include Howz, Kemuri, Cascade 3D, Tynetec and Canary Care.

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Table 2. Inferred changes in routines and ADLs of older people living alone.

	NILM detection	Potential behaviour/ ADL changes	Possible health or wellbeing risk/relevance (examples only)
Long term changes	Use of kettle or other appliances during the night	Sleep problems/ disturbances	• Mental health problems • Neurological deterioration • Pain associated with arthritis
	Later first use of kettle	Mobility problems/ sleep problems	• Neurological deterioration • Pain associated with arthritis • Deterioration in underlying disease
	Leaving appliances on (e.g. oven)	Memory problems	• Deterioration in mental health • MCI/dementia
	Appliance use at a time or on a day where previously there had been none	Decline in social relationships/ dropping out of activities	• Social isolation • Deterioration in mental health • Deterioration in underlying disease
	Stops using microwave and oven	Eating problems	• Indication of new condition (e.g. gastrointestinal) • Deterioration in underlying disease (e.g. cardiovascular disease/COPD/diabetes)
	Stops using kettle	Less intake of fluid (dehydration)	• Urinary tract infection • Falls • Exacerbation of cognitive impairment
	Decreased or irregular use of appliances	Difficulties performing ADLs	• Mental health problems • Cognitive impairment • Neurological problems • Deterioration in underlying disease • Worsening pain associated with underlying condition
	Increase of energy consumption during late evenings and nights	Agitation, restlessness and confusion	• 'Sundowning' syndrome (Alzheimer's/dementia)

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	NILM detection	Potential behaviour/ ADL changes	Possible health or wellbeing risk/relevance (examples only)
Short term changes	Later first use of kettle	Difficulty getting up in the morning	• Sickness/infection (e.g. UTI) • Increase in pain associated with underlying disease (e.g. arthritis)
	Stops using appliances altogether	Inactivity	• Fall/incapacitation • Sepsis • Acute deterioration from underlying disease (e.g. cardiovascular/COPD) • Stroke
	Sudden decrease in use of appliances	Lower capacity for ADLs	• Sickness/infection (e.g. UTI) • Deterioration from underlying disease (e.g. cardiovascular/ COPD) • Worry about falling • Failure to take prescribed medications appropriately • Adverse drug interaction

Machine-learning approaches with smart meter data in health or care services may sound like tomorrow's world. In fact, an informal care offering with smart energy technology has recently become a commercial reality in Japan, devised by the Sony spin-off B2B company Informetis and provided by the Tokyo Electric Power Company (TEPCO). With a European research lab based in Cambridge, Informetis is running field trials of very similar technology in Europe, with a commercial launch of its product planned for 2021.

Clinical monitoring using smart energy data remains in the research phase. This is true of most clinical AAL solutions incorporating machine-learning technologies, including those currently being tested by Bristol's Sphere project[2] and the multi-site EU Gatekeeper project,[3] running in eight cities in seven countries.

2. See Sphere Project website: https://www.irc-sphere.ac.uk/
3. See Gatekeeper Project website: https://www.gatekeeper-project.eu/

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In focus: smart energy monitoring and dementia

Smart energy data research has seen focus on dementia due to its high prevalence and profound economic impact on health and care systems. The first in-depth clinical research of NILM in dementia care – using energy data exclusively – was undertaken by Liverpool John Moores University (LJMU) in collaboration with Mersey Care NHS Foundation Trust. Two individuals with mild to moderate dementia, under the care of Mersey Care FT, were recruited for the six-month trial in 2016. It was a priority that the NILM system should not require conscious interaction from the monitored individuals at any stage.

During the trial, routines were detected and a total of four sleep disturbances observed, with anomalous activity including use of the kettle and toaster between midnight and 5 am. This kind of behaviour change observed over a longer period could give clinicians important insights into the speed and progression of dementia. A longer-term trial with 50 patients over 30 months is now planned to test appliance detection across different households, and further explore the clinical validity of the monitoring approach (Chalmers et al., 2019).

In Austria, the research, service and consulting firm Solgenium is likewise planning dementia research using NILM. Partnering with several healthcare providers, it aims to recruit 500 participants and explore data fusion with other easily accessible data, using the same principle of machine-learning techniques to inform clinical alerts and decision-making. The firm has already trialled NILM to monitor sleep problems and track the effectiveness of sleep medication, and was recently awarded EUR 1.35 million for a phase 2 pilot.

Scaling home monitoring technology

Consumer access devices (CADs) and Clamps

Smart energy monitoring systems most commonly proposed in health and care contexts involve high-frequency data sampling from within the home. In the LJMU and Mersey Care study, above, data was collected at 10 second intervals, simulating the data collection capability of a commercially-available consumer access device (CAD).

A CAD is a secure device that is normally used to provide the consumer with tariff information and almost real-time data from the smart meter on energy consumption. A CAD can transmit data either inside the property or to an external internet location (e.g. via Wi-Fi, 3G or 4G cellular) and can in theory be

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used to enable detection of high-energy appliances, such as a kettle, microwave, toaster, electric oven and washing machine. CADs are already installed by some energy providers and have shown evidence of increased energy engagement in homes (without any NILM disaggregation service), in comparison to the more basic in-home-display (IHD) units (BEAMA, 2018).

The use of current clamps, which can sample at second and sub-second frequencies, is also a consideration for NILM services, since with such equipment a monitoring system has potential capacity to recognise low-energy devices invisible to a CAD, such as the television, computer and hairdryer, use of which could be important indicators of wellbeing status.

Smart meter communications only

The utility of lower-resolution energy data, as routinely transmitted from the smart meter to the energy provider at 15-, 30- or 60-minute intervals (depending on country), is also a subject of ongoing research. This research is important because a telehealthcare monitoring system requiring no extra hardware in the home beyond the smart meter itself is a tantalisingly scalable proposition.

One approach, explored by researchers at Sweden's Blekinge Institute of Technology, is to detect deviation from daily routines from aggregated (one-hour) energy consumption data alone, without any appliance disaggregation (Nordahl, 2019). The health technology provider Howz and East Midlands Academic Science Health Network (ASHN) are to test a similar approach in a forthcoming pilot in Leicester,[4] with 30-minute electricity data sourced from the Data Communications Company (Smart DCC).[5] If considered useful, the technology will be offered to the public as a free app-based informal care monitoring service, with option to purchase an upgrade with in-home AAL technology (2020health 2020).

Another important research stream is examining techniques for the disaggregation of appliance loads from smart-meter level data. For instance, researchers at the University Strathclyde, Glasgow, have succeeding in disaggregating a wide range of home appliances from hourly data – even when unlabelled loads are contributing to meter readings (Zhao et al., 2020). Whether such methods can be replicated at scale and without prior knowledge of installed appliances is the subject of future research.

4. The pilot is being supported by NHSX and Surrey and Borders Partnership NHS FT. Recruitment will be undertaken by a large GP practice in Leicester, and evaluation by De Montfort University.
5. Smart DCC connects smart meters to energy suppliers, network operators and other authorised service users.

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1.2 Population-level screening and monitoring

Managing the health and care needs of an aging society probably presents the greatest challenge to health equity and service quality in the UK. Another critical challenge is meeting the needs of the most vulnerable, regardless of age, at a time when health inequalities are widening (PHE, 2018). Our social imbalances are leaving some families both fuel-poor and food insecure, which can have a profound impact on the health and wellbeing of children (BMJ 2019). COVID-19 has simply further exposed health inequalities, with risk of serious illness higher among those living in more socioeconomically deprived areas, and among black, Asian and minority ethnic groups (PHE, 2020).

Fuel poverty and cold living conditions can worsen many common physical and mental health problems for people of any age. Around 25,000 excess winter deaths occurred in England, Wales and Scotland in the 2018/19 winter, with leading causes being respiratory diseases (such as pneumonia), circulatory diseases, and dementia and Alzheimer's disease (ONS 2019; NRS 2019). In the case of children, risks to respiratory health, weight and susceptibility to illness are all increased (PHE, 2014).

There is evidence that the smart meter infrastructure will present a unique opportunity to gain insights into cases of fuel poverty, neglect and unhealthy living conditions. If a building's thermal efficiency rating (EPC rating) is known, then a combination of daily average electricity and gas readings, together with external air temperature and solar irradiance data, may be enough to detect the under heating of homes.

But what if a building's EPC rating is unknown? A recent study suggests it may be possible to remotely establish the whole-house heat transfer coefficient of a dwelling with exactly the same data sources (Chambers, 2017). In other words, a building's thermal efficiency rating and indications of cold living conditions could be identified entirely remotely. Whereas an EPC rating is in theory a one-off assessment, the screening and monitoring of health-related living conditions would need to be ongoing to be of real value.

People living in the most deprived areas spend nearly a third of their lives in poor health, compared with only about a sixth for those in the least deprived areas.

Public Health England, 2018.

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The health and wellbeing utility of this technology could be enhanced by in-home smart temperature and humidity sensors, which would enable insights on risks of damp and mould (BSECC, 2015).

Scaling the technology

In theory, population-level screening and monitoring approaches described above could be achieved with electricity and gas data channelled by Smart DCC, which offers nationwide connectivity with 99% coverage. No visit to the screened or monitored property would be needed, unless temperature and humidity sensors were required.

An authorised Smart DCC user (organisation), with customer consent, can access not only ongoing 30-minute aggregated data, but also a household's historical energy data (stored on the meter for a 13-month period), and other potentially relevant metadata held by the DCC.

Metadata relating to low credit thresholds and emergency credit activation could also be provided to local authorities at an aggregated level, without consumer consent. Data would offer valuable insights on streets and districts where many may be struggling to meet need. Consensual use of such metadata would allow insight of need at the household level.

The UK government's SMETER competition,[6] testing the use of smart energy data to assess the thermal performance of homes, is an opportunity for exploring energy and health sector synergies and could hasten the scaling of remote screening. (Data acquisition in SMETER is via the DCC or an in-home CAD.)

Energy-health synergies could also be explored through the Smart Energy Research Lab (SERL), which expects to have recruited 10,000 consenting GB households to its Observatory Panel by early 2021. It aims to offer high-resolution energy data to support the development of a reliable evidence base for observational and longitudinal studies across the socio-technical spectrum (Webborn, 2019). There are already several existing projects that could be used to simultaneously explore energy and health/wellbeing outcomes, including exploring wintertime comfort in UK homes (see full report for current projects).

6. Smart Meter Enabled Thermal Efficiency Ratings (SMETER) Innovation Competition was launched by BEIS in 2018 and is due to conclude early 2021.

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The energy sector could play an important role in screening, given its existing responsibility to identify customers' potential vulnerability. Vulnerability may be associated with being of pensionable age, living with young children or a disability, struggling financially or temporarily being less able due to an accident (Ofgem, 2019). Suppliers and network operators are expected to offer Priority Services Register (PSR) services covering a wide range of needs, not all of them financial. In the future, their services could be extended to help determine suitability for local government help or even a remote care solution.

1.3 Self-monitoring and home safety

Self-monitoring lies at the heart of smart home energy management systems (HEMS). These systems typically communicate through smartphone apps and are designed to make consumers more energy aware. In this way, consumers can take steps to reduce costs by reducing energy consumption and/or shifting energy use to more cost-effective times of the day, where time-of-use tariffs are in operation.

HEMS could facilitate consumer wellbeing, health and safety in a number of ways:

- Individuals and families may improve their energy footprint and reduce fuel poverty, in turn improving their general wellbeing (Robinson et al., 2017).
- Using data analytics described above (1.2), systems could enable detection of unhealthy living conditions and follow with practical advice on keeping warm or signposting to winter fuel help (such as the Warm Home Discount Scheme[7]) or to government insulation grants.
- Using a NILM approach (above, 1.1), systems could recognise atypical behaviours indicative of health or wellbeing problems; alerts could follow for self-help or recommendations for a health check-up or GP appointment.
- Systems could detect appliances left on, especially ovens, which can run up costs and waste energy very quickly. Continued forgetfulness could be recognised by the system, and if representing a change in behaviour, an alert generated to prompt follow-up with a GP.

7. The Warm Home Discount Scheme is available to those receiving the Guarantee Credit element of Pension Credit and to some low-income households that meet their energy supplier's criteria for the scheme.

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Scaling the technology

NILM-based HEMS are already commercially available in some countries but have little application to health and self-care. Most appear to use some form of current clamp or sensor to enable detection of both high- and low-powered devices, offering more control, scheduling capability and user information. There are clear opportunities to explore the capacity of the system to support self-care, particularly where this integrates water consumption, but such data-heavy and relatively expensive approaches may have limited scalability in the near future.

A cheaper (and more scalable) option could be the CAD, with its lower sampling rates still sufficient to guide energy users towards safer and healthier routines. This could likewise integrate water data and other environmental data, where available.

The CAD or clamp approach may or may not require the participation of the energy sector, though energy providers would themselves be well placed to invite participation in self-care schemes at the point of new contracts.

2. Regulation, privacy and consent

Research by the Public Interest Advisory Group (PIAG) indicates that consumers find it a challenge to determine the risks and benefits involved with the use of their energy data, but on the whole consider smart meter data to be less sensitive than other forms of data.

This may change if smart meter data becomes 'health and care data'. Consideration will need to be given to:

- appropriate regulatory oversight, possibly including third party certification with the National Cyber Security Centre's Cyber Essentials Scheme;

- General Data Protection Regulation (GDPR) for individuals: (i) to have a clear affirmative act (opt-in) to consent to health and care use of data; (ii) to be informed when personal data are being collected and processed; (iii) to object to certain processing activities (including profiling) and to automated decision-making; and (iv) to be safe from unsolicited marketing and exploitation; and

- continuity of services when switching provider, where care monitoring is included.

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Regulators will need to examine a unique set of concerns in what is likely to be an evolving offering. For example, the right to safe and secure data portability (GDPR, 2018, Article 20) raises the question as to what extent personal data fed into machine learning systems (and behavioural insights derived therefrom) should be transferrable to other parties at the request of the consumer, particularly to ensure continuity of services.

Continuity of services when switching provider is another concern, especially if energy companies offer provision of informal care monitoring systems (as in the case of TEPCO[8] in Japan). The bundling of services across the domains of energy and care could itself have a chilling effect on switching, so clear regulatory guidelines would be required.

At the same time, where individuals move out of tele-monitored properties, privacy assurances will be needed for new occupants who do not want the smart meter or CAD left 'live' or 'open' to the monitoring of their energy patterns.

In sum, an ongoing process of reassurance is likely to be required to allay users' fears and concerns and ensure appropriate regulatory oversight keeps in step with developments in the field.

3. Health, wellbeing and economic benefits of smart energy solutions

It is evident that the smart meter infrastructure offers significant potential in remote health, care and wellbeing monitoring. Whether used as a stand-alone solution or as one component within a more comprehensive AAL system, it may make health and care services more responsive, affordable and agile in the long term.

Its potential value to dementia care is well worth considering, bearing in mind that one third of people in the UK with dementia do not have a diagnosis (nearly one half do not in Wales), and around one in three people with a dementia diagnosis are not receiving appropriate NHS follow up support (Alzheimer's Research UK 2018; Age UK, 2018).

8. TEPCO: Tokyo Electric Power Company

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> **Dementia costs the UK £26 billion a year. Two thirds of the cost of dementia is paid by people with dementia and their families.**
>
> **Alzheimer's Society, 2014**

Early detection of dementia could be facilitated by a telecare service aimed at supporting independent living. The same service may then be able to provide disease progression monitoring, and enable the monitored party to live longer and more safely in their own home, delaying transition to the care home setting. A study from 2009 calculated that if 10% of care home admissions were prevented in England, savings by year ten would be around £120 million in public expenditure (social care) and £125 million in private expenditure (service users and their families), a total of £245 million (Banerjee & Wittenberg, 2009). Dementia costs the UK £26 billion a year. Two thirds of the cost of dementia is paid by people with dementia and their families (Alzheimer's Society, 2014). Could monitoring systems using smart energy data lighten the economic burden for sufferers and their families?

In contexts of both informal and formal care, smart energy monitoring systems present opportunities to mobilise social networks and social capital, particularly by involving family members and trusted friends as 'first responders' to alerts and possible health concerns. This is an important consideration for sustainable healthcare. Insights from smart energy monitoring could also support workforce productivity (e.g. of community care workers and nurses) in terms of identifying, prioritising and addressing client needs.

Reductions of hospital admissions, together with earlier post-operative discharge, resulting from AAL monitoring with smart energy as a component, is another cost saving opportunity.

Savings could also be realised through population screening approaches. Our review has noted the health and economic impact of cold homes. In 2012, research from Age UK found that cold, damp and mouldy homes were costing the NHS in England £1.36 billion every year in hospital and primary care, particularly due to their devastating impact on older people's health (Age UK, 2015). Children living in the same conditions are 1.5 to 3 times more likely to develop symptoms of asthma than children living in warm and dry homes (PHE, 2014). Childhood asthma has significant adverse impact on the child's daily activities and schooling, as well as family life and finances.

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It is impossible to say what effect a population-level screening service using smart energy data might have on improvements to population health. But what is surely evident is that a service that can exploit technology already in place is a unique opportunity to try and improve health status and even save lives.

4. Conclusion and recommendations

Despite promising proposals and compelling demonstration of technological potential, research and development in the use of smart meters in health and care contexts remains embryonic.

A lack of progress worldwide, particularly in health monitoring contexts, is perhaps in part due to the fact that government and institutional funding opportunities have not recognised the specific multi-disciplinary requirements for rigorous clinical research involving smart energy data and machine learning. Research projects often end up being siloed in either energy or health domains. To evidence real-world scalability and clinical validity, projects require collaboration spanning computer science, engineering, energy and healthcare.

Government and the UKRI might want to facilitate cross-sector innovation by creating research funding opportunities that explicitly link energy and health outcomes. Exploring opportunities to share data securely across existing research data portals such as the Smart Energy Research Lab (energy) and UK BioBank (health) would further facilitate cross-sectoral research.

BEIS's SMETER innovation competition, aiming at the remote measurement of buildings' thermal efficiency, could provide a springboard to investigate health and wellbeing potential through the same technology. So too with its current Smart Energy Savings (SENS) competition, where innovative products and services, aiming at energy savings in homes, may also be exploited for health and self-care opportunities.

In this way, the UK government can seek to meet critical targets across both energy and healthcare simultaneously through the smart meter roll-out. Health and wellbeing targets include reducing excess winter mortality; addressing system pressures from an aging population; supporting family caring needs; and giving timely support for those with Alzheimer's, dementia, Parkinson's, MS and other disabling long-term conditions. Research suggests these vulnerabilities and conditions can all be supported by information derived from smart meter data.

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Recommendations

1. With the possibility of the use of smart meter data in telecare as early as 2021, Ofgem should review and ensure robust data security, privacy and consent (opt-in) regulations around the sharing of energy data with named third parties delivering care services and data analytics.

2. Ofgem should consider a requirement that named third-party telecare monitoring services using smart meter data register with the relevant property energy provider, regardless of data acquisition method. The energy provider should then ensure discontinuity of third-party access to smart meter data upon any changes in residency, to guarantee data protection of the new occupant(s).

3. The Department of Health and Social Care, NHS England, Office for Life Sciences and other institutional funders should support wider clinical investigation of non-intrusive load monitoring (NILM) techniques within remote health monitoring systems. Funding opportunities need to target a range of neurological conditions with the aim of tracking disease progression, as well as post-operative and medical intervention home-monitoring.

4. Government, UKRI and other funders should consider ways to facilitate cross-sector innovation by creating research funding opportunities that explicitly link energy and health outcomes. Exploring opportunities to share data securely across existing research data portals such as the Smart Energy Research Lab (energy) and UK BioBank (health) would further facilitate cross-sectoral research.

5. Public-funded research should investigate how smart energy and smart water data may together provide deeper insights into activities of daily living and health risks associated with personal neglect. Trials need to involve families and carers, who are crucial to engagement and the mobilisation of social capital.

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6. BEIS should consider wider societal applications of Smart Meter Enabled Thermal Efficiency Ratings (SMETER) technologies during its evaluation phase and dissemination of learning (January 2021). It should consider how these might scale as a screening and monitoring solution for the detection of possible fuel poverty, neglect and poor living conditions that contribute to illness.

7. Supporting the Clean Growth Strategy, government and Smart Energy GB should consider public and media awareness campaigns to promote the importance of smart meters in tackling fuel poverty and health inequalities, given their potential to rapidly identify properties in need of energy performance upgrade (to EPC bands C or B). The campaigns should clarify the potential health benefits of a smart meter infrastructure, not just financial and environmental benefits.

8. BEIS should investigate one-second data sampling capability for future upgrades to smart electricity meter technology. Faster sampling rates may have potential to further increase home energy management engagement and facilitate remotely-activated health and care monitoring solutions without need for any additional hardware installation.

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