MAKING ENERGY **SMARTER**

USING SMART ENERGY SYSTEMS
IN THE TRANSITION TO NET ZERO

UNIVERSITY OF LEEDS

Why Smart Energy Systems?

The growth of renewable and distributed sources within the UK's energy system, along with the drive for all sectors to decarbonise, brings challenges to balance fluctuating supply and demand, and smarter systems are needed to manage this complexity.

Maximising the efficiency of a changing energy system relies on a wide range of underpinning technologies – including big data and machine learning – that need to be brought together to create smarter systems.

The use of micro-grids managed through smart systems can help bring together distributed energy sources and enable remote rural or island communities across the world to decarbonise their energy systems.

A better understanding of how people will engage with new energy systems and the business models that can support them is pointing the way to the changes needed in policy, legislation and regulation to make these systems both just and sustainable.

Identifying the optimal mix of renewables

Alderney is the third largest of the Channel Islands, with a population of around 2000 people. Electric power on Alderney island is centrally generated by 8 × 450 kVA diesel generators and supplied through an extensive network consisting of underground cables. The island is reliant on imported fuel for all its energy generation. University of Leeds researchers used PyEPLAN to determine the optimal low-carbon micro-grid for the island, to minimise reliance on imported fuel. The researchers used data on the island's energy demand and weather patterns over an average year to draw up a range of scenarios combining wind, solar, battery storage and existing diesel generation. The tool was able to identify what mix of these four technologies would create the best low-carbon investment plan for the island, taking account of energy distribution losses in the cable network (5).

Micro-grids in sub-Saharan Africa

The University of Leeds is involved in a project with partners in Uganda, Tanzania, Republic of the Congo and Indonesia to help develop micro-grids for energy distribution in off-grid communities such as the Watoto Suubi village, an orphanage in Uganda with 180 homes onsite. The research draws on previous work in Indonesia (which looked at small-scale renewable energy on islands that can't be reached by large-scale energy infrastructure) and transfers the lessons learnt to the design and implementation of micro-grids in the context of sub-Saharan Africa.

Currently, barely 10 percent of the rural population in Tanzania, Uganda and the Republic of Congo have access to electricity. The micro-grid design focuses on a combination of biofuel generators and solar energy.

The research uses an integrated approach to ensure that the design of the system is easy to maintain, will last with minimal ongoing investment, meets diverse community energy needs and is resilient to natural hazards (6).

Enabling Technologies

Smart energy systems rely on a range of underpinning technologies, such as different fuel sources, advanced energy conversion, storage and integration technologies, smart metering, sensors, and information and communication technology.

Key to all smart energy systems is the use of big data analysis, artificial intelligence and machine learning. Without advances in these areas and the expertise to apply these technologies within smart energy systems, we will struggle to meet the challenges inherent in our transition to low carbon energy sources.

- Learning multi-modal data collected from intelligent meters and sensors will strengthen our understanding of human behaviour and energy consumption patterns, while also providing a rich source of geographic information. Consumer behaviour is one of the main areas of expertise in the Leeds Institute for Data Analytics (LIDA).
- Machine learning tools can be used to help drive energy efficiency. For example, machine learning algorithms in battery driven small sensor nodes like Internet of Things devices for monitoring could reduce the energy consumption of data centres which account for five percent of the world's total energy consumption.
- New online trading mechanisms, such as the distributed ledgers used in blockchain trading, could be adapted for managing the large numbers of transactions between energy consumers and producers in a distributed system, to ensure they are secure and transparent.

Energy storage will also be a key part of any future energy system, as this will allow for increased electrification of energy demand for heating, cooling, transport and industry. But smart systems are needed to identify where and monitor how storage should be used safely and effectively to ensure it contributes to lowering CO_2 emissions. Previous research has shown that even if storage has a 100 percent round-trip efficiency (7) (and there are in reality losses associated with charging and discharging any storage device) it can actually result in increased CO_2 emissions if a high carbon source is used to charge it and then output from a low carbon source is reduced when the storage is discharged.

Smart battery management

One of the key challenges for battery applications in power grid and transport electrification is safety, with battery fires and explosions in electric cars, electric buses, aircrafts, and grid-tied battery storages reported worldwide.

Traditional battery condition monitoring and management tools can no longer meet more stringent safety requirements. Researchers at Leeds have developed a series of smart sensing, big data analytics and machine learning tools and techniques for smart battery management (8).

- Based on laboratory research which demonstrated significant difference between battery internal and shell temperature for high C charging and uneven thermal distribution for both single battery cell and battery modules, the Leeds team has developed combined thermo-electric models and high-accuracy joint estimation methods for both battery internal temperature and state of charge (SOC).
- To replace the conventional and ineffective CCCV (constant current and constant voltage) battery charging strategy widely used in commercial battery management systems, the team has developed a constrained multi-objective battery charging control framework based on coupled thermo-electric battery models. This achieves better battery management in terms of safety, health and efficiency, paving the way for modernising battery management.
- Battery health monitoring is essential for battery management and cascading utilization, yet it is also problematic due to many influencing factors. The Leeds team has developed a pruned convolutional neural network approach assisted by transfer learning. This achieves over twenty percent estimation error reduction and over eighty percent computation saving, showing that big data analytics can be applied to battery health monitoring.
- To tackle the issue of limited measurement and electromagnetic interferences on traditional battery sensors, the Leeds team in partnership with City University has developed a novel fibre optical sensing technology, achieving multipoint condition monitoring to improve both thermal management and state estimation accuracy.

Making the best use of storage

Research at Leeds drew on data from National Grid's regional Carbon Intensity API and ELEXON's P114 dataset to look at the source of electricity consumed in each of Great Britain's 14 electricity distribution zones for each half hour period over the course of a year (2019).

The researchers then assessed the impact of three different storage operating scenarios:

- Load levelling, where storage is charged during low demand and discharged during high demand
- Wind balancing, where storage is charged at times of high wind output and discharged during low wind output
- Reducing wind curtailment, where storage is charged using excess wind generation that would otherwise be curtailed and discharged at times of high demand.

They found that wind balancing may lead to increased CO2 emissions, while emissions were reduced the most when storage was used to reduce wind curtailment in regions with high levels of fossil fuel energy generation. This showed that choice of storage types and use needs to be made on a regional basis and can contribute to reducing emissions as the UK moves from fossil fuel to low carbon energy sources (9).

Computational tools for self-managed energy systems

Two of the main challenges faced by smart grids are cascading failures in the transmission system and regulation of demand response programmes.

To optimise power flows using coordinating smart transformers and load shedding, the transformers need to communicate and make collective decisions about how to re-route power flows from one line to the other. The way to do this is through computational tools, such as EPOS ***(Economic Planning and Optimized Selections)***.

EPOS is a decentralized combinatorial optimisation tool, developed by a University of Leeds researcher, which can be used in sustainable and self-managed distribution systems to autonomously generate a set of options for collective decision-making among agents. An agent might be a consumer, a piece of software or a hybrid system that locally generates in a self-determined way a set of plans that define how a set of resources are allocated.

EPOS can be a useful tool to handle the challenges of system stability and reliability of renewable energy resources. Utilities could crowd-source the regulation process via EPOS by enabling consumers to engage in the demand-response programs, load-shedding options via smart phones or other embedded smart controllers without collecting and processing their personal data. EPOS agents could also interact and collectively select a schedule that reduces costs, power peaks or shifts demand to times of high availability in renewables (10) (11).

epos-net.org

End Users

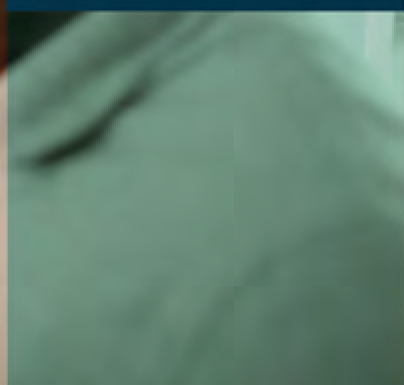
Reducing energy consumption and moving to low-carbon sources relies on changes in behaviour and energy usage by end users. Smart energy systems are key to this process, helping end users to reduce the CO2 emissions linked to their energy use.

Transportation uses 40 percent of final energy consumption in the UK (4), covering cars, aviation, trains, buses and shipping. Electric vehicles will help to reduce the carbon emissions from transport, but mass use of electric vehicles and the installation of large numbers of new charge points will require coordination through integrated smart energy management systems.

For example, the University of Leeds is involved in a pilot project led by SSE Enterprise to transform a North London bus garage into a mini power station, using the batteries of 28 electric double decker buses to feed up to 1 megawatt of energy back into the grid.

Manufacturing industries, both large scale and SMEs, are also intensive energy users, often of multiple energy sources. Some also have the potential to be producers, through combined heat and power, solar or wind. Many small and medium sized enterprises (SMEs) struggle to know what steps they should take to reduce their energy usage within a complex manufacturing process. A smart energy system using high-tech sensors and complex data analysis can identify the highest energy use and find where savings can most effectively be made.

Domestic buildings account for 30 percent of energy use in the UK (4). While upgrading of the housing stock is required to reduce this, smart energy systems will also play a role. Through smart energy systems, private households can better manage their energy use and integrate energy generation, storage and use. However, the growing ‘prosumer’ phenomenon in the UK has largely been driven by subsidies, which is not a sustainable model. The regulatory, financing and institutional governance landscape of the UK lags behind these changes, which is inhibiting the development of new business models (12).



Smarter bread-making

Irwin's Bakery is a medium-sized business with around 350 employees that has produced bread and cakes in Northern Ireland since 1912. Electricity is one of the primary energy sources for the company's six main production stages: mixing, transport of the dough into the prover via a hoist, proving, oven baking, removal of the hot bread (depanning) and then cooling in the chiller.

Irwin's are piloting a tool called the Point Energy Platform, developed by researchers at the University of Leeds. The platform monitors and records the energy consumption of manufacturing processes at various levels of granularity using a combination of current transformers, interfaces to the existing meters and customised smart meters. The meters connect via WiFi with an on-site server and then the data is sent to the cloud for analysis.

Additional sensors are installed on the largest production line, which record the real-time performance of the process. Using cutting-edge radio technology, these measurements are gathered from inside sealed industrial control panels.

The researchers and the business can see daily and weekly patterns for each machine, how hard each machine is working at any one time and for how long, and when they are turned off or on standby. Through computer modelling, the researchers are able to identify strategies to optimise production while making the most efficient use of the machines, and schedule energy demand to make use of preferential tariffs to reduce cost.

Policy to support prosumers

Recent developments in technology such as the diffusion of smart meters, Li-ion batteries, peer-to-peer trading platforms and electric vehicles are opening up a range of new value propositions, which in turn are beginning to be exploited by a variety of new business models. These business models rely on managing a complex set of values for consumers that reach deeper into their lives than traditional tariffs. To be successful, business models must manage this complexity if they are to be adopted by the disengaged majority.

Extensive analysis of the growing 'prosumer' market by researchers at the University of Leeds has identified barriers to their implementation, which need to be addressed through improved legislation and guidance. The research highlighted the risk that mainly affluent, educated and engaged consumers will capture the benefits of low carbon business model innovation and exacerbate existing socio-economic inequalities (13). The researchers' policy recommendations (12) are:

- Government should assist in removing barriers to new value propositions, such as those that involve multiple energy vectors and long-term service-based models.
- Current legislation that requires mandatory 28-day switching should be reviewed in light of the multiple benefits that long-term energy service contracts can provide.
- The regulator should expedite cost-reflective distribution network tariffs: developing prices that better reflect the actual costs of network services, without unfairly charging wider energy customers.
- The system operator should create a new route for independent aggregators to access the balancing mechanism, making it simpler for small-scale flexibility providers to access ancillary service markets.
- Customers cannot trade electricity between themselves without a third-party licensed supplier. This should be reviewed in the light of the potential for peer-to-peer models, requiring alternative models than the 'supplier hub' approach.
- The smart meter rollout should ensure that meters have sufficient interoperability with these emerging models, systems and markets.

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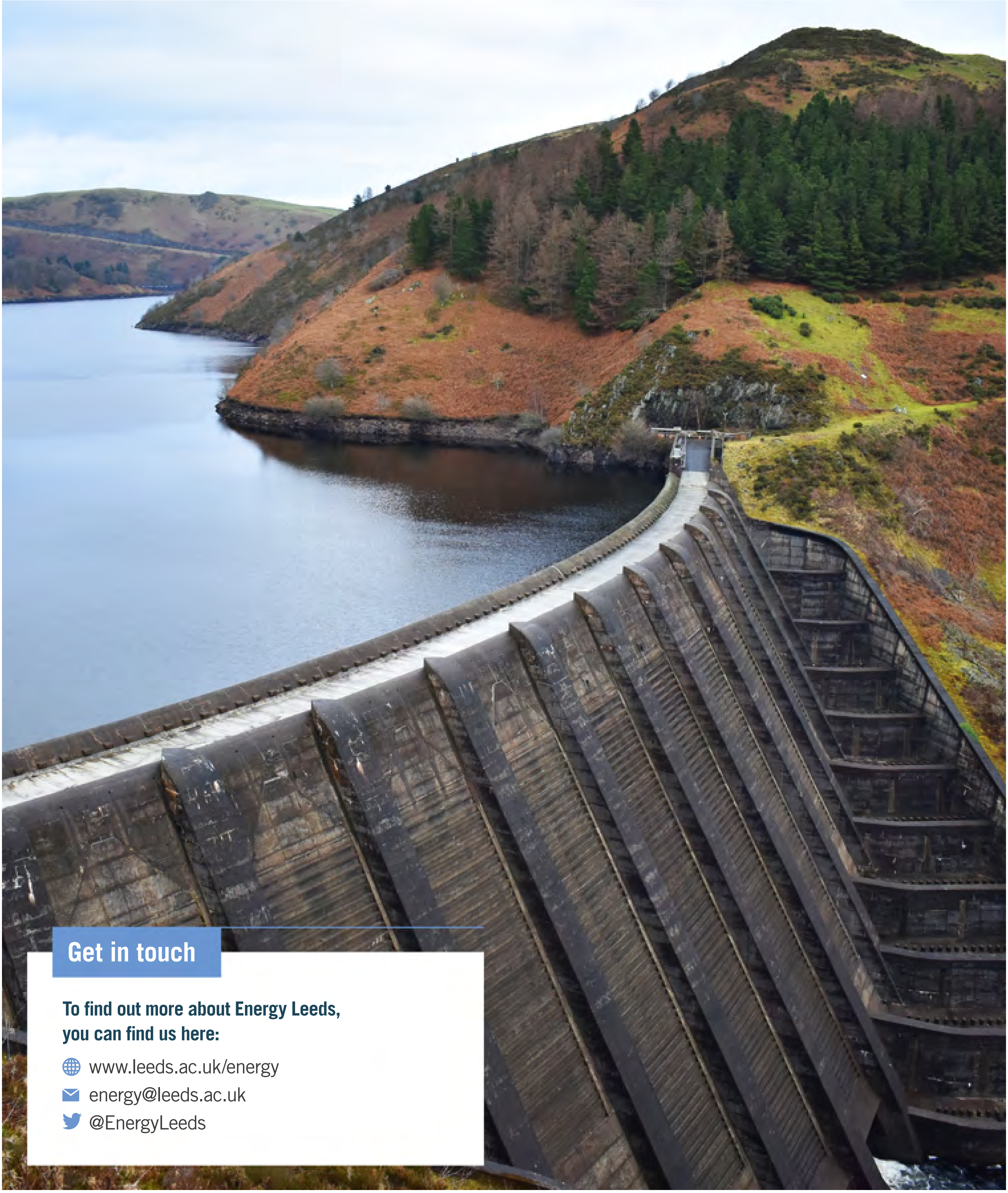

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