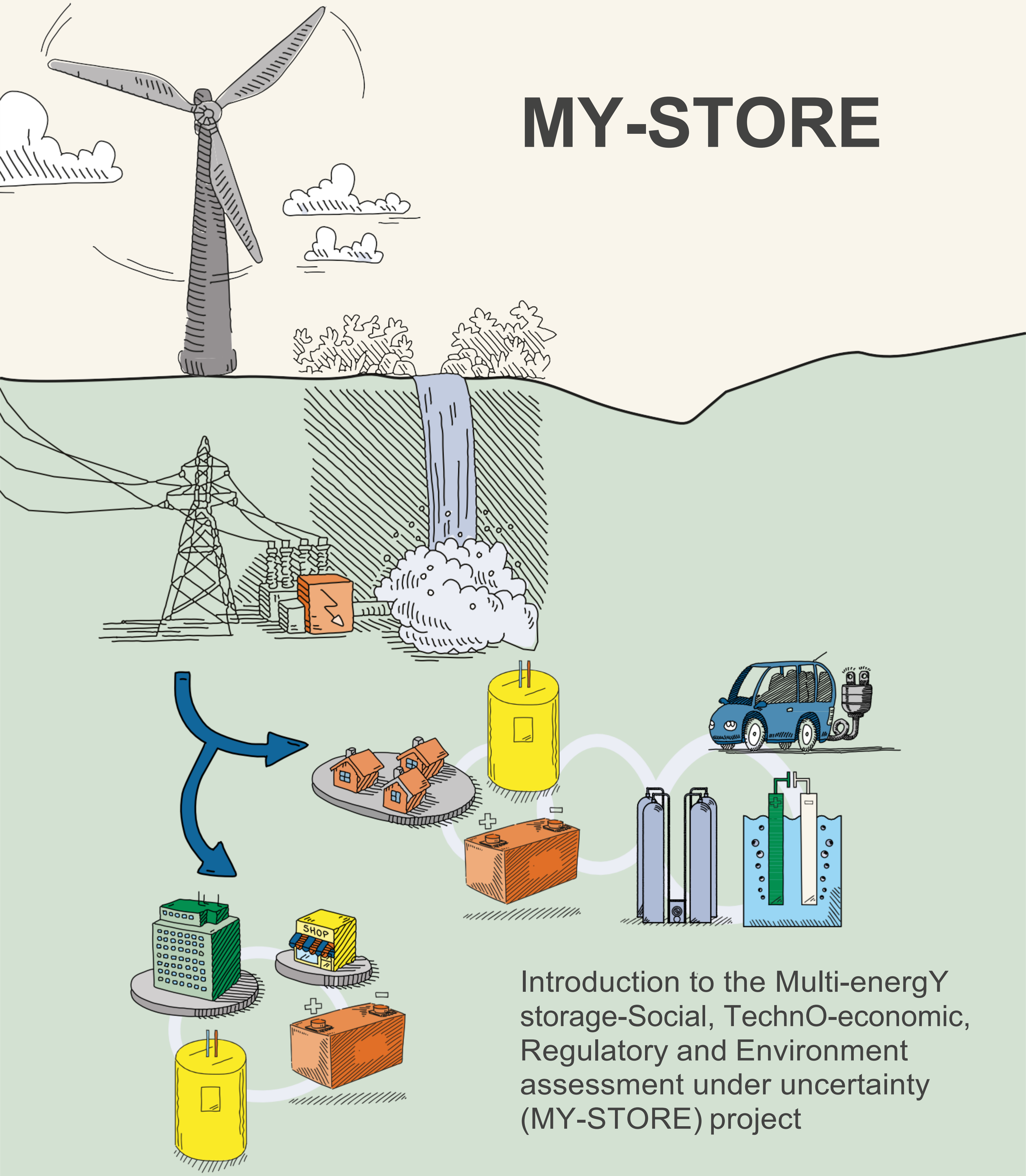
MY-STORE



Introduction to the Multi-energY storage-Social, TechnO-economic, Regulatory and Environment assessment under uncertainty (MY-STORE) project

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Multi-energY storage-Social, TechnO-economic, Regulatory and Environment assessment under uncertainty (MY-STORE) project

The UK has committed to transition to net-zero greenhouse gas emissions by 2050. This hugely ambitious target implies wholesale change to the UK economy, particularly the energy sector. According to the Committee on Climate Change[1]:

- all electricity will need to come from low-carbon sources including a significant proportion from variable output renewables like solar and wind power
- surface transport will be predominately electric, or hydrogen powered*
- nearly all buildings will need to be heated by low-carbon heat including scenarios where there is significant amount of electrical or hydrogen heating.

The transition to net zero is a challenge and an opportunity. A future net-zero energy system will need to operate far more flexibly than today's system. The Committee on Climate Change in their net-zero technical report estimate that improvements in system flexibility have potential to bring electricity system costs down by £3-8 billion/year by 2030 and £16 billion/year by 2050[2].

It is widely recognised that energy storage has the potential to play a crucial role in supporting the transition to net-zero energy systems, and helping to meet these challenging targets. Storage, alongside other approaches such as demand side response, interconnectors and flexible generation, reduces the costs of the net-zero transition in three ways:

- It improves utilisation of low-carbon generation, meaning that less needs to be built to meet demand;
- It provides a range of energy system balancing and ancillary services, displacing expensive and carbon intensive options such as fossil-fuelled peaking plants;
- It avoids or defers the need to reinforce constrained networks.

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* For hydrogen to be net zero, it would need to produced without carbon emissions, for example either via water electrolysis using zero-carbon electricity or via steam methane reformation with carbon dioxide capture and storage.

The crucial role of energy storage across multiple services and markets is reflected in UK energy system scenarios out to 2050. National Grid's (GW) Future Energy Scenarios (FES) estimate that electricity storage capacity could range from 14 Gigawatt (GW) ("Steady Progression" scenario) to 28GW ("Community Renewables" scenario), compared to under 4GW today[3]. National Grid also suggest that up to 25% of homes could possess thermal storage by 2050 in their net-zero analysis[4].

Energy storage can be applied at all levels of the energy system; from co-location with transmission-connected generators, through use in district heating schemes, to behind-the-meter installations in homes and businesses. As a result, participants across the energy value chain (e.g. generators, network operators, end users) can all benefit from energy storage.

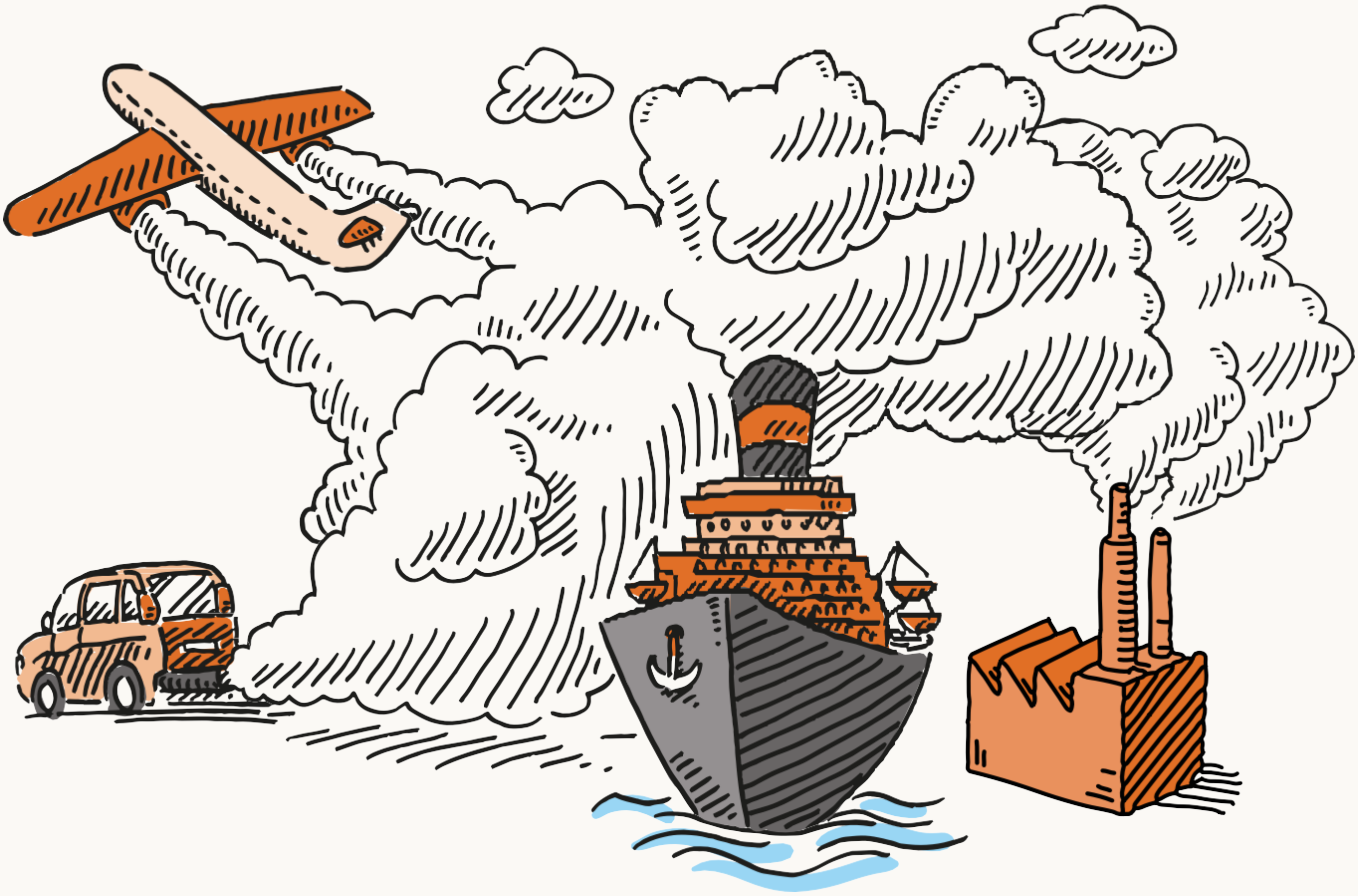
For energy storage to realise its potential it will require policy, regulatory and market frameworks aligned with the benefits storage can deliver. In turn, decisions to change elements of such frameworks will need to be evidence-based.

The MY-STORE project[5] brought together leading academics and industry to explore and provide new evidence on the role of storage in the UK in the short-, medium- and long-term transition to a decarbonised economy. MY-STORE aimed to address the multiple factors preventing the development of these frameworks. In order to do this, and understand the value and benefits of storage in an increasingly complex and integrated system, we combined a range of innovative modelling approaches capable of giving new insight on individual and aggregated storage devices across multiple scales and vectors in the context of important environmental and social factors. This provides unique insight into sustainable business cases for different types of energy storage and the commercial, regulatory, and institutional settings that can facilitate storage deployment.

In this document we summarise the key messages, themes and new evidence from five-years of interdisciplinary research, derived from a significant body of peer-reviewed published academic work. These recommendations provide new insight into the potential, value, business case, barriers and policy and regulatory framework for energy storage across vectors and scales.

Achieving net-zero

Achieving net-zero is a whole energy system challenge, but today is often viewed as a challenge of separate sectors and technologies. Our work has shown that thinking in an integrated fashion across electricity, heating and transport at multiple scales, and using the full toolbox of available technologies and approaches, can reduce the cost of net-zero transformation, achieve multiple outcomes and avoid unintended consequences.

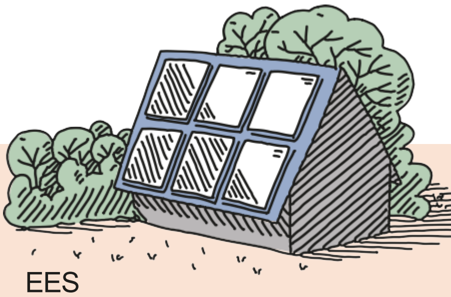


Achieving the 2050 net-zero greenhouse gas target in the UK requires energy services to be decarbonised across electricity, heating and transport. These systems are currently relatively separated as heating is predominately fuelled by natural gas and transport by liquid fossil fuels. Going forwards they are expected to become more integrated as heating and transport become increasingly electrified with electricity supplied more and more by variable output renewables. To accommodate these changes and ensure the balance between electricity demand and supply, electricity networks will need to become more ‘flexible’ and ‘smarter’, where generation and/or consumption patterns can be modified to respond to an external signal (such as a change in price) and provide a service within the energy system.

We have demonstrated the importance of thinking across energy services. For example, between transport and electricity services, we have shown that electrolysers that use electricity to produce hydrogen can vary their output in line with available renewable electricity and in response to system needs, such as constraints. This displaces fossil fuel generation, reducing system costs and greenhouse gas emissions as well as providing a low- or zero-carbon fuel for transport[6,7].

We have found that in local energy systems, where numerous intelligent energy assets such as smart heating systems, electric vehicles and energy storage devices are connected, that there is benefit in advanced distributed control solutions compared with central control and dispatch. For example, we developed a distributed control framework for the optimal coordination of thousands of small batteries, demonstrating that a distributed control approach resulted in an improved frequency response, satisfying all technical requirements and still accounting for degradation and reward aspects[8,9].

We have also applied theories of socio-technical transitions to derive new insights on the future wide-spread adoption of a range of energy storage technologies currently under demonstration. Enabling the transition to a low-carbon energy system requires opening-up to all forms of storage wherever there are feasible applications, harnessing the potential for storage to support the shifting of energy across electricity, transport and heat networks. For this to be achieved, broader regulatory frameworks are required to enable storage providers to access the full range of markets where storage can play a role, and in so doing facilitate its role in the future of the energy supply in the UK[10].



Different technologies within this section:

EES
Electrolysers

EES
Thermal storage, batteries

EES
Electric vehicles

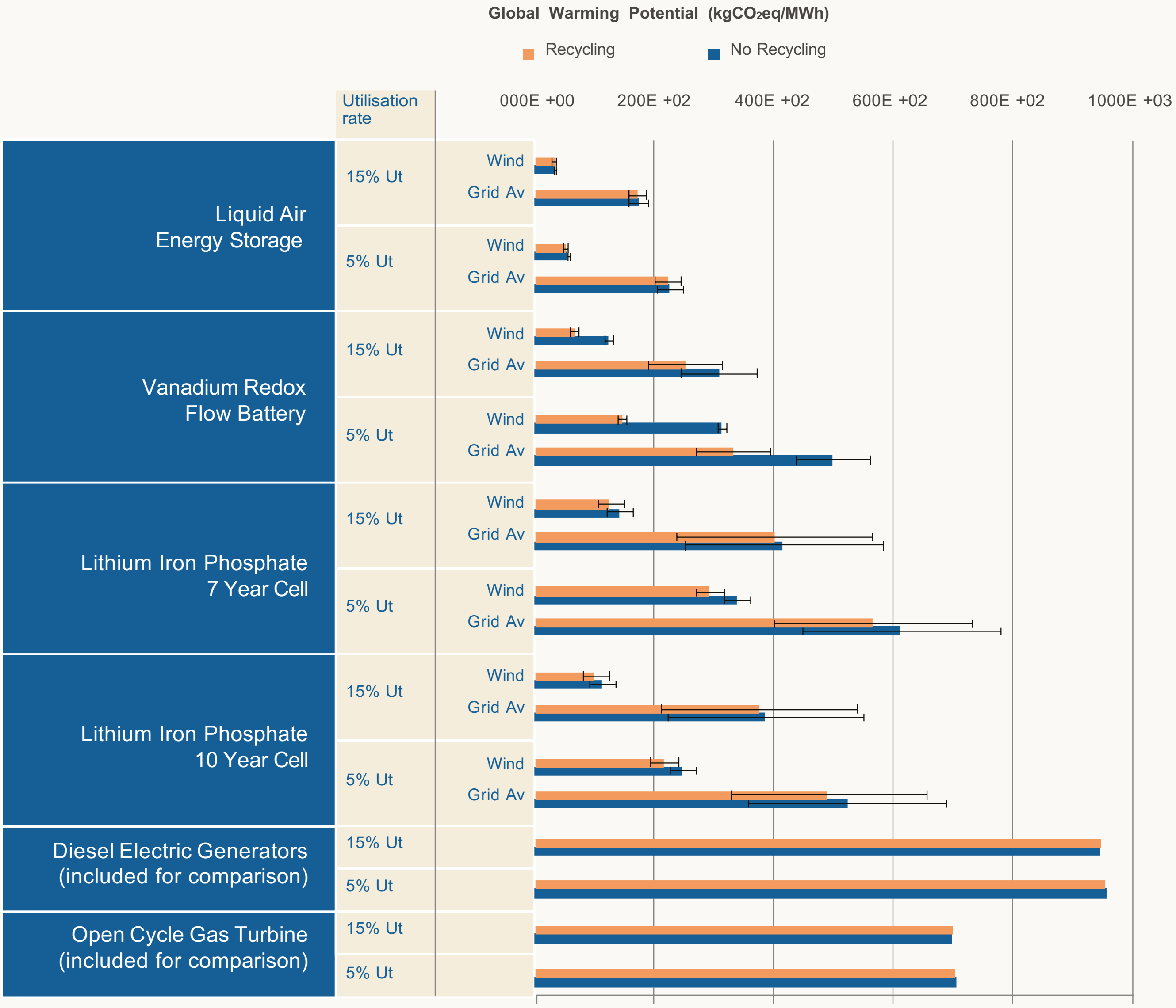
Key Messages

Whole-systems approach

A whole-systems approach is needed when considering storage solutions. No single technology is the answer to net-zero energy transitions, solutions depend on the place and local and national objectives, not just cost and overall carbon emissions.

Figure 1. Life Cycle Assessment of Global Warming Potential of various different storage technologies[11]

Reproduced from Jones, C., Gilbert, P., and Stamford, L., Assessing the Climate Change Mitigation Potential of Stationary Energy Storage for Electricity Grid Services, Environmental Science & Technology 2020 54 (1), 67-75 (2020). DOI: 10.1021/acs.est.9b06231, CC-BY Licence



The focus of research and development activities can dictate the commercial viability of different storage technologies, which in turn can shape how the transition proceeds[10]. Comparisons of different energy storage solutions are often limited to considerations of their costs and round-trip efficiencies. However, the environmental performance of storage solutions varies widely depending not only on the technology, but also the context in which it is used. Therefore, it is important to also evaluate and compare energy storage technologies with one another, not only against traditional technologies, since certain solutions may have a greater decarbonisation potential.

To do this, it is essential that a wide range of metrics beyond cost and round-trip efficiency are considered when evaluating energy storage technologies. Energy and material inputs to manufacturing, product life span and recyclability can all be significant factors for overall environmental performance. We demonstrated that for the systems we assessed, storage is always preferable on environmental terms compared to the use of diesel and open cycle gas turbines, based on per MWh output to the grid[11]. Yet, our Life Cycle Assessment (LCA) approach showed that redox flow batteries and liquid air energy storage (LAES) provide both recyclability and scalability benefits over Li-ion batteries and these benefits translate into broader environmental benefits (see Figure 1 for the key results).

MY-STORE work demonstrated that it is also important to consider the context in which the storage solution is being applied. Under-utilisation of the storage asset over its lifetime increases the overall environmental impact per MWh of electricity; how the technology will be used may, therefore, determine which technology will be appropriate. Scale, too, should be considered when choosing an energy storage solution. For example, when LAES is scaled up to provide large grid scale services its global warming potential per MWh decreases and it shows environmental advantages over Li-ion batteries and redox flow batteries.

These findings reveal how crucial it is to expand the range of metrics for comparing energy storage solutions beyond just cost and round-trip efficiency. A more comprehensive LCA approach is necessary, not only in determining R&D activities but also in policymaking, to avoid precluding certain technologies from the transition and missing out on greater environmental benefits. Such an approach can also help to determine whether different storage solutions should be used in different places depending on utilisation needs, scale and available resources. Policy incentives for storage should also consider how to get high utilisation levels and renewable energy inputs to charging, as well as how to promote technologies which can be recycled at the end of their lifetime.

Different technologies within this section:

EES
Vanadium redox flow batteries

EES
Liquid air energy storages

EES
Lithium-ion & ‘conventional’ lead acid batteries

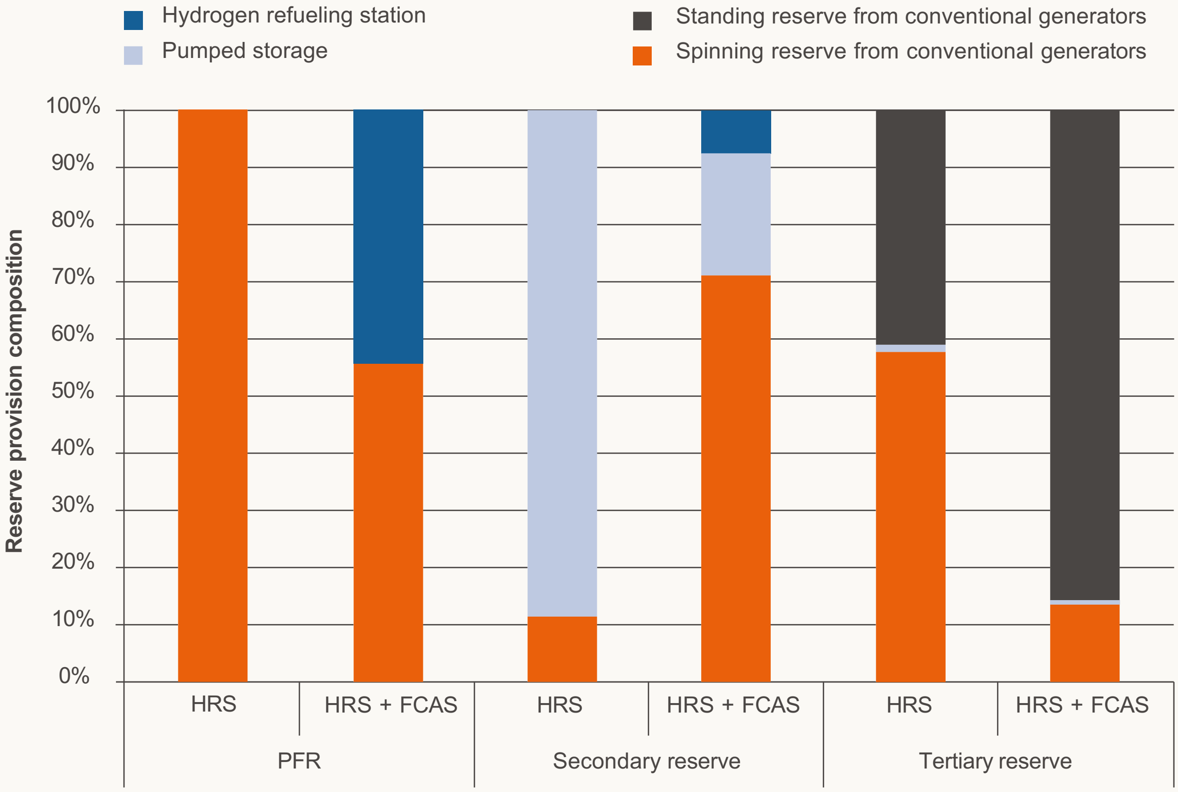
Key Messages

Untapped opportunities

There are untapped opportunities to be realised by adopting a cross-vector approach, including heat storage, hybrid gas-electricity heating systems and through using renewable power to make hydrogen. Adopting an integrated approach could reduce decarbonisation cost and improve the performance of net-zero energy systems.

Figure 2. Integrating Hydrogen Transport Fuel Assets into the Power Network: potential contribution of Electrolysers at Hydrogen Refuelling Stations to Power System Reserves[7]

From Zhang, L., Clegg, S. & Mancarella, P. Modeling of electrolyzers in hydrogen vehicle refueling stations for provision of ancillary services. IREP’2017 Symp. pp 1–7 (2017).



The bars represent the potential contribution of different storage vectors for Primary Frequency Response (PFR), Secondary and Tertiary reserves if electrolysers were either used to provide i) Hydrogen Refuelling Services (HRS) only or ii) a combination of both Hydrogen Refuelling Services and Frequency Control Ancillary Services (FCAS).

For each of the three types of reserves the chart shows the changes in the mix of storage providers with and without the contribution of electrolysers. If electrolysers were used for frequency control ancillary services, then they could provide over 44% of PFR, 7% of secondary reserves and 0.2% of tertiary reserves. This could reduce the reserve provision burden of conventional generators.

The transition to a net-zero energy system entails increasing electrification of heating, cooling and mobility[10] and in parallel the decarbonisation of electricity is creating both a driver for and a loss of energy system flexibility. Different vectors offer new approaches and challenges for flexibility because they have different characteristics and timescales – for example the instant response required to balance electricity compared with the inter-seasonal nature of heating demand[12]. This affects how different vectors access different value streams in the energy system. Our work has demonstrated that electricity, heat and hydrogen storage can all play an important role in reducing the cost and improving the performance of energy systems as they transition to net zero.

For example, a system comprising of an electric heat pump and a domestic hot water storage tank can be utilised to provide flexibility to the electricity grid in the form of Demand Side Response (DSR) by increasing or reducing heat pump demand in response to price signal[12,13]. This has the dual benefit of reducing electricity system stress, whilst at the same time lowering energy costs by shifting heat pump demand to lower cost periods to heat water for storage and subsequent use of this heat store during high cost periods (thus reducing electricity demand at peak times). Furthermore, increasing heat pump demand when required can contribute to the avoidance or reduction of renewable generation curtailment[13].

We have also demonstrated that that at times of reduced renewable generation, a hybrid heating system could switch to use gas in place of electricity as the fuel source thereby reducing the need for more expensive peaking plants resulting in a 24% reduction in peak conventional generation[14]. In a future system where hydrogen is more abundant, this could also mitigate the carbon emissions from the fuel switching if the hydrogen is produced without carbon emissions[2].

Related to the previous point, conversion of electricity to hydrogen using electrolysers also provides a flexible new load that can provide frequency balancing services and DSR to the electricity system[7]. Electrolysers do this by varying their output in line with renewable energy generation and electricity system requirements[6]. The rate at which they can vary their output is comparable to batteries. For example, electrolysers at refuelling stations could be installed alongside hydrogen storage to convert renewable electricity to hydrogen[6,7]. The produced hydrogen could then be stored prior to use in vehicles. MY-STORE work presented a model to assess how the power system can help decarbonise the transportation sector and how refuelling stations can contribute to power system reserves[6] (see Figure 2 for the key results of this analysis).

Different technologies within this section:

EES
Electrolysers

EES
Thermal energy storage

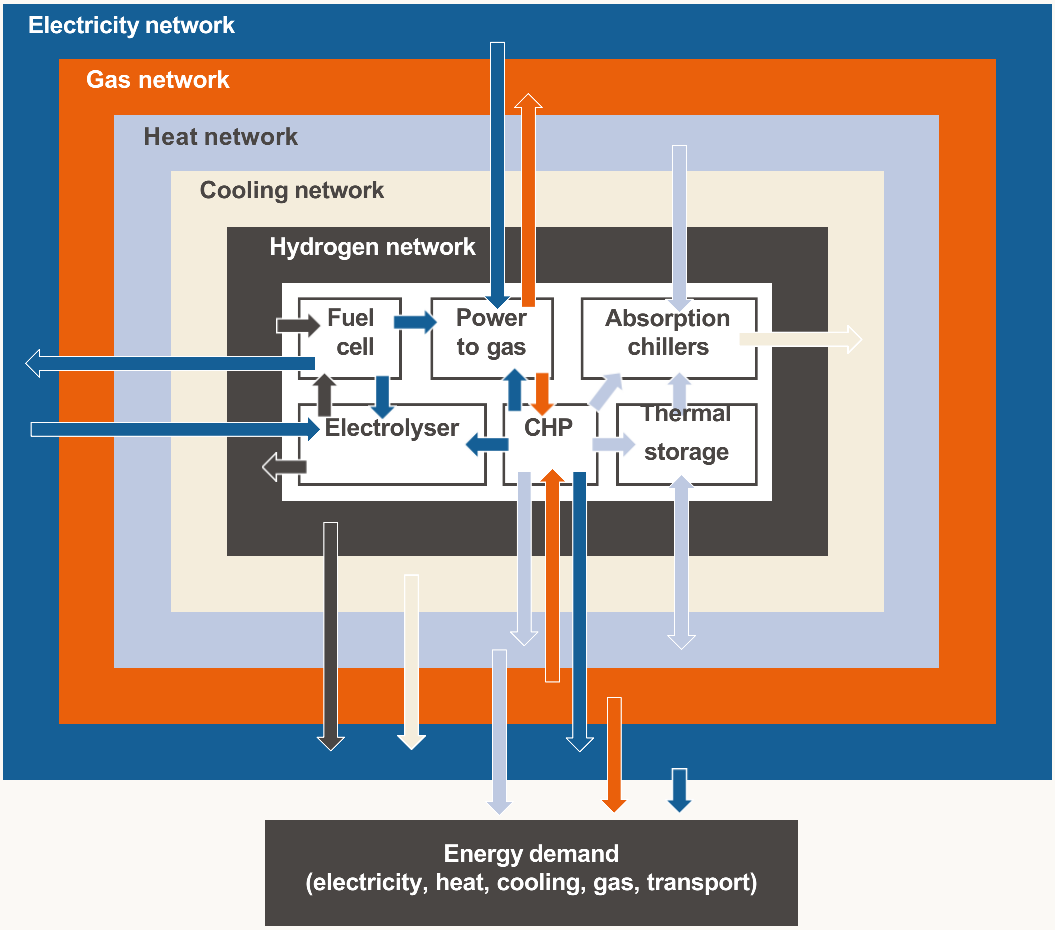
Key Messages

Storage

Storage can play an important role in creating smart districts and distributed control could be a key approach to delivering this. Integrating electricity and heat storage in smart districts can alleviate network constraints and accommodate more local demand and generation. Distributed control of thousands of energy assets can provide valuable energy system services without unduly affecting consumers.

Figure 3. Interactions between energy vectors[12]

Reprinted from Good, N., Martínez Ceseña, E. A. & Mancarella, P. Ten questions concerning smart districts. Build. Environ. 118, 362–376 (2017). with permission from Elsevier https://doi.org/10.1016/j.buildenv.2017.03.037

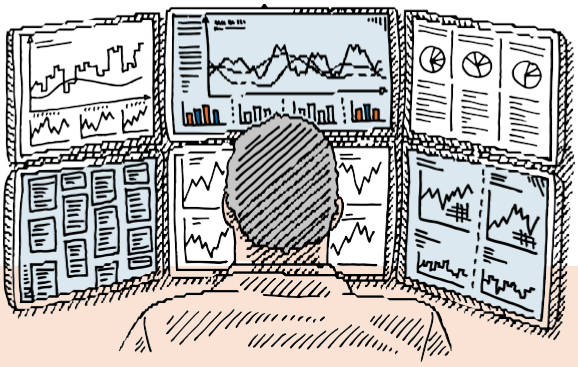


An anticipated feature of the transition to net-zero energy is the concentration of energy technologies locally including renewable electricity generation, electric vehicles and decarbonised heating and cooling. National Grid's "Community Renewables" Future Energy Scenario[4], which depicts a low-carbon but not net-zero energy system, suggests that by 2050 up to 58% of renewable electricity generation will be connected at the distribution-network level (compared to 29% today), and that electricity will dominate domestic heating and road transport.

This localisation of energy creates an opportunity for 'smart districts' to optimise these local energy systems for both local and national benefits. A smart district is a local or community energy system that adopts various enabling 'smart' technologies, supporting the transition towards a smart grid. Smart districts vary from place to place in terms of resources, local network capacity, socio-economic circumstances – thus they also vary in how they could operate, and what value and benefits they can realise, both locally and nationally[12].

In MY-STORE we have developed smart district optimisation models that consider multiple energy services, including thermal and electrical storage. We have demonstrated that local thermal energy and battery storage can be employed to alleviate distribution network constraints and also minimise costs[15]. We have also shown that different local flexibility options can be used to integrate more electric heat pumps into a capacity constrained smart district that is managed as a community energy system, while maximising its revenues from multiple markets/services[16].

Smart districts comprise numerous intelligent and controllable assets, such as batteries, electric vehicles and heating systems. The control strategy used to coordinate such assets determines the services they provide, their lifetime and efficiency. We have demonstrated that a distributed control approach can be applied to thousands of assets with excellent results[8,9]. For example, we were able to model the coordination of thousands of small batteries to provide enhanced frequency response in the required time, satisfying all technical requirements and still accounting for degradation and reward aspects. We have also shown that through a properly designed coordination strategy, multi-energy storage systems can satisfy occupant thermal comfort requirements whilst providing valuable grid services, such as short term operating reserve[8,9].



Different technologies within this section:

TES
Hot water tanks

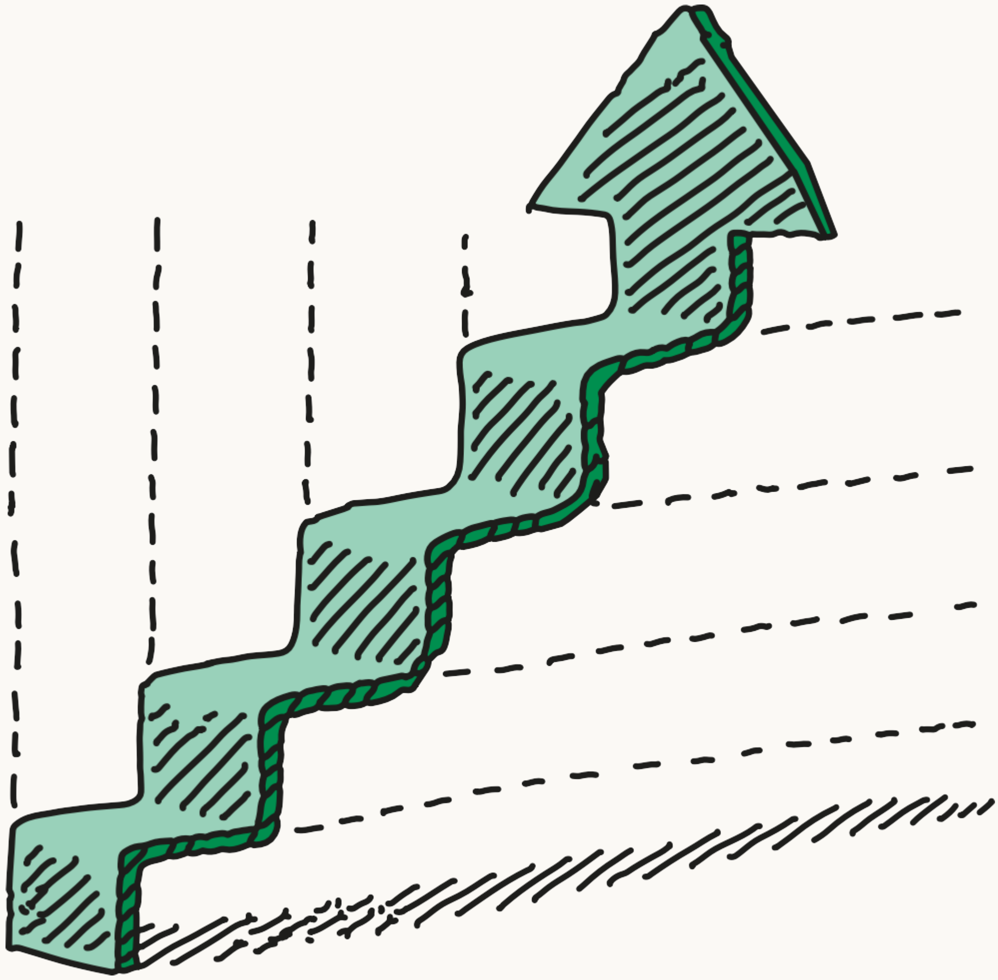
EES
Vanadium redox flow batteries

EES
Lithium-ion & 'conventional' lead acid batteries

Key Messages

New users

A range of new users, including households, could potentially be involved in net-zero energy system operation and optimisation. User-centric approaches should be applied to ensure that all users are able to participate and that energy services are not unduly affected.



Future net-zero energy systems, where electricity supply is increasingly from variable output renewables and where transport and heating are substantially electrified, will require flexibility to operate within limits and to reduce overall costs. In order to maximise the sources of flexibility, including that from citizens, it is likely that price-signal based incentives will be needed. Such price-signals would reflect the needs of the whole energy system and should incentivise providers of flexibility to shift consumption in time (e.g. by using a battery), to another vector (e.g. fuel switching as described above) and/or curtail demand (e.g. turning something down, or off)[12].

To be able to participate, energy assets must be able to provide the services required by the system and in a timely fashion. This may require that devices, including those in homes and small businesses, be automated so that response is guaranteed. However, if the energy asset is, for example, a heating system or an electric vehicle in a home, automation could potentially affect user energy services, which in turn could limit participation (for example, if participation becomes an annoyance)[12,16].

Relating to the last point, our modelling has demonstrated that new electric heat pumps can be integrated in network constrained smart districts using flexibility available from local technologies such as heat pumps, electric boilers and electricity and thermal storage. A key finding from this work is that some of the best results are obtained where some degree of building temperature flexibility is allowed (e.g. the building is allowed to slightly overheat or cool, impacting internal temperature). This demonstrates the potential contribution to flexibility that changes to the level of energy services can bring, but also the importance of designing such propositions around user-needs so that participation is maximised[16].

A similar result was found in our work modelling a distributed optimal control framework for coordinating multiple diverse storage units. Here we showed that multi-energy storage devices can be optimised to satisfy occupant comfort requirements whilst delivering valuable services to the Electricity System Operator[9]. In both these cases, these are modelling outputs: the effect of variance in thermal comfort on users requires further analysis, and new assessment metrics that are relevant to more integrated energy systems[14].

Different technologies within this section:

EES
Thermal energy storage

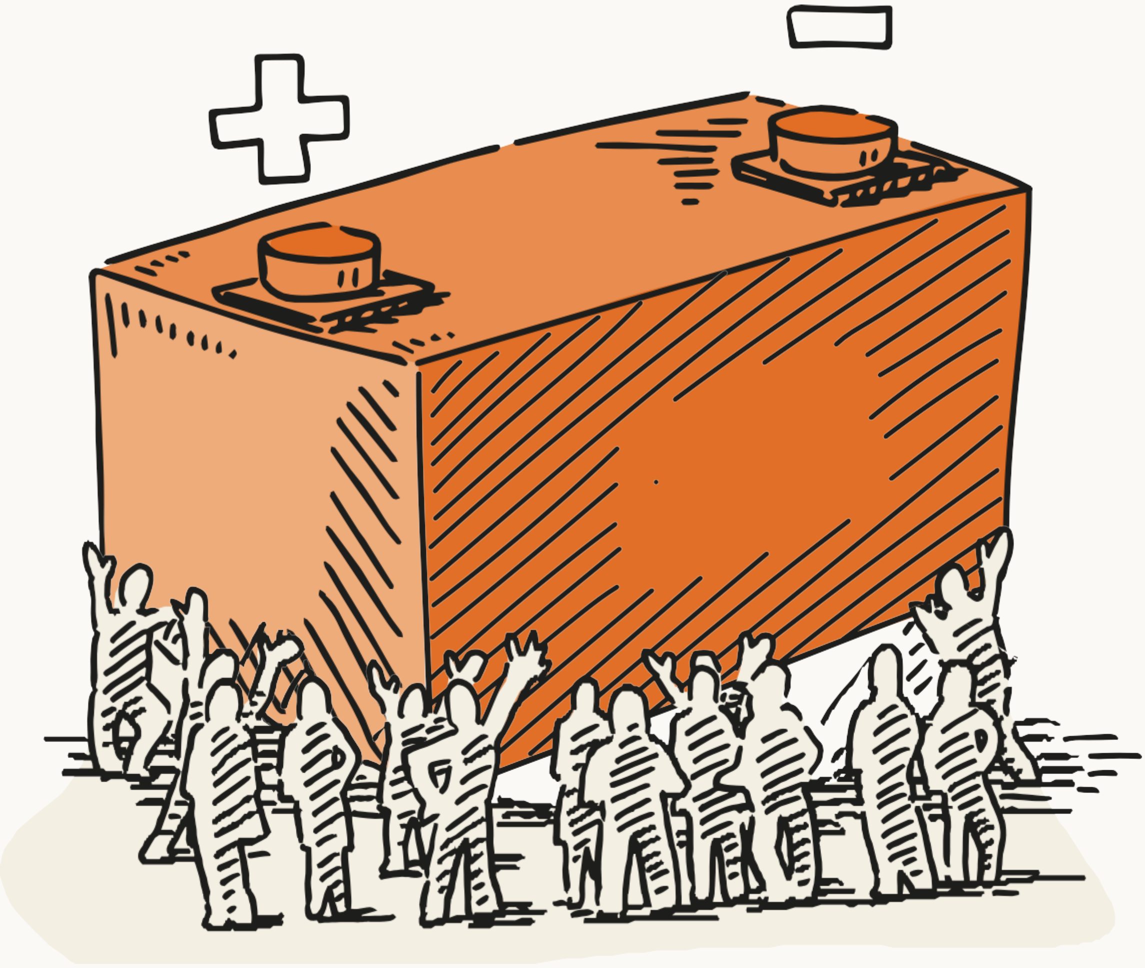
EES
Batteries

EES
Electric cars

Key Messages

Energy storage

Energy storage will not emerge rapidly unless there is a supportive policy, regulatory and market structure in place. Additionally, there needs to be a level playing field for all energy storage technologies.



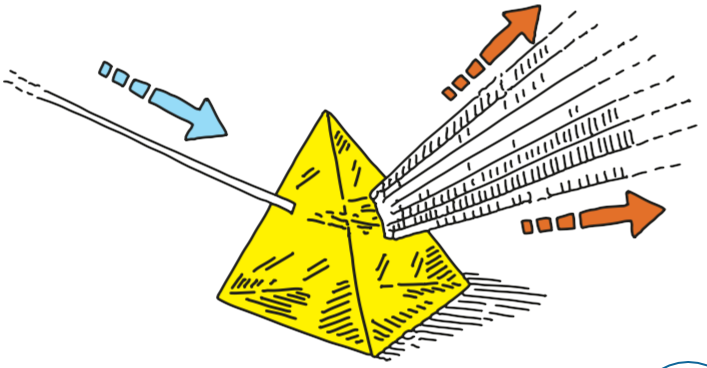
The energy system is undergoing a period of rapid change, driven by new, disruptive technologies and external disruptions including the need to address climate change. This disruption has opened a space for energy storage. However, for storage to realise its potential, policy, regulation and markets will need to be aligned with the benefits it delivers[10].

Energy storage can deliver multiple energy system services. An issue is that the markets for these services are fragmented (for example across wholesale, balancing, capacity, ancillary services and flexibility markets) and can require exclusivity, thus energy storage may not be able to access all its potential value. In our paper on smart districts, we postulate that a transactive energy approach, where dynamic price signals may apply throughout the energy value chain (for example including network-related locational price signals, alongside energy and ancillary service price signals) could improve the business case for storage and other smart approaches[13].

Within the family of energy storage technologies, we have also identified that the focus of BEIS, National Grid and Ofgem has been heavily weighted towards electricity energy storage and its application within electricity systems. We conclude that other technologies, such as thermal energy storage technologies, can offer similar benefits and services and should be considered alongside batteries in the development of markets, policy and regulatory frameworks. The risk in not doing this is that technologies that are less developed, or less market-ready, could be locked out, resulting in lost opportunities to accelerate decarbonisation across energy systems and achievement of climate change targets domestically and internationally[10].

Our work exploring barriers and opportunities for energy storage in the transition towards net-zero energy highlights the need for a vision for the role of all forms of storage in delivering energy system transformation[10]. Through our work we have demonstrated that storage can play multiple roles in the transition, including:

- Improving the environmental performance of the energy system
- Optimising within and across electricity, heat and transport energy services across multiple objectives
- Delivering energy services to a range of markets and energy system needs
- Involving a range of existing and new users, including citizens
- Enabling the potential of smart districts.



Concluding remarks

Key results from the MY-STORE project suggest that tremendous opportunities are available to cost-effectively decarbonise the UK energy system by deploying multi-energy forms of storage, with also the concrete possibility of developing new business cases for both old and new technologies even in current market environments. This requires a whole-system, all-services approach that energy policy and regulation should foster to unlock the true energy storage potential across energy vectors, sectors, and markets.

The summary given here provides a snapshot of the research work conducted and some of its outputs.

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