Smart Solar Homes: The Journey to Net Zero

Realising the benefits of smart energy technologies in our homes

Solar Energy UK

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Advance Further Energy Ltd. a consultancy focused on enabling low carbon transitions providing services on new energy solutions. Our specialist areas include technical and commercial modelling of solar, battery, heat, grid systems and microgrids. AFE works with start-ups, suppliers and standards organisations.

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Foreword

Chris Hewett, Chief Executive, Solar Energy UK

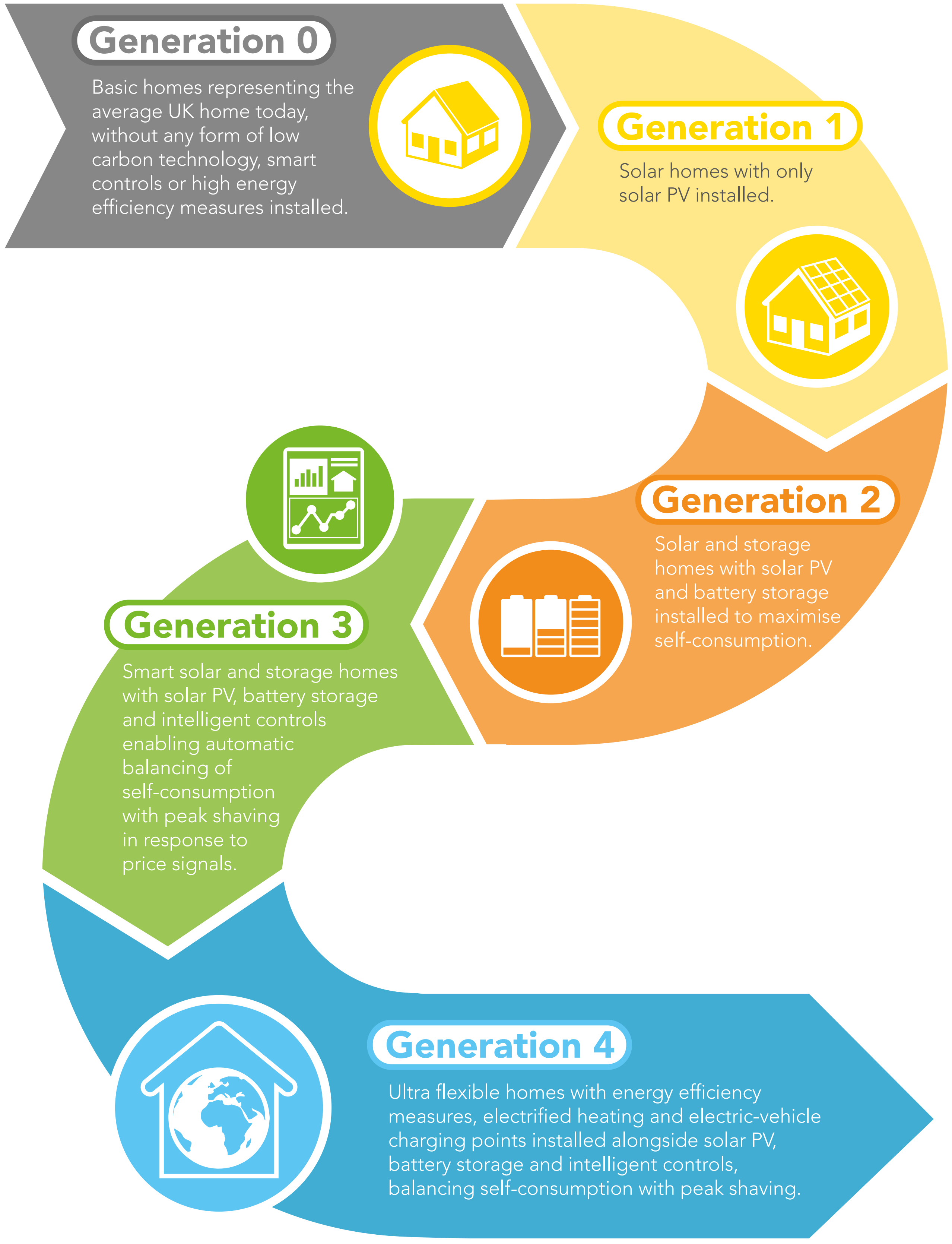
The UK electricity system is rapidly changing to one that will be primarily powered by solar and wind by 2030. We now have an opportunity to make our homes active contributors of the flexibility needed to maximise the potential of renewables, rather than be simply passive consumers of electricity. The evidence is here - deploying smart energy technologies across the country not only cuts carbon and helps households save on their energy bills, but can actively minimise spikes in electricity demand, which place the grid under intense stress. Therefore, it is not simply the homeowner who stands to benefit from solar and energy storage, but everyone.

MCS Charitable Foundation an independent UK-wide charity with a mission to accelerate adoption of renewable energy and low carbon technologies. Set up by government in 2018, the Foundation owns the MCS standards scheme for renewable energy at buildings scale and uses the profits from that scheme for its grant-giving and charitable work. The Foundation is particularly focused on initiatives that build capacity, grow public awareness and promote innovative solutions and uses evidence from the projects it supports to lobby for changes in public policy.

> "The policy landscape needs to support innovative methods of deploying technology that will accelerate the path to net zero emissions. MCS Charitable Foundation chose to award funding to this project to provide important new evidence to inform the debate on decarbonising our homes."
>
> **Adrian Ramsay, Chief Executive Officer, MCS Charitable Foundation**

Larkfleet Smart Homes the innovation arm of the award-winning housebuilding and development company Larkfleet Group, developing leading-edge energy technology ecosystems and business models for domestic housing. We are designing and developing energy services for householders that will provide comfort, value for money and sustainability to make the group's housing developments fit and ready for the climate challenge ahead.

> "At Larkfleet, we have a history of sustainable innovation and we are looking to the future in much the same way. This research fits well with our plans and supports our R&D work to develop a smart home offer for our future customers."
>
> **Karl Hick, Chairman, Larkfleet Group**


Generation 0
Basic homes representing the average UK home today, without any form of low carbon technology, smart controls or high energy efficiency measures installed.
Generation 1
Solar homes with only solar PV installed.
Generation 2
Solar and storage homes with solar PV and battery storage installed to maximise self-consumption.
Generation 3
Smart solar and storage homes with solar PV, battery storage and intelligent controls enabling automatic balancing of self-consumption with peak shaving in response to price signals.
Generation 4
Ultra flexible homes with energy efficiency measures, electrified heating and electric-vehicle charging points installed alongside solar PV, battery storage and intelligent controls, balancing self-consumption with peak shaving.

Contents

Executive summary

This report highlights the consumer and system-wide benefits of homes equipped with smart solar and storage technologies.

The UK's journey to net zero presents society with an unprecedented challenge and will significantly change many aspects of people's lives. Achieving a zero-carbon economy by 2050 requires the rapid decarbonisation of energy use in the heating and transportation sectors, alongside the rapid deployment of clean renewable technologies.

In the UK, the growing use of technologies such as electric vehicles (EVs) and heat pumps will drive electricity demand up. More electricity consumption will lead to heightened stress on the power system, particularly when electricity use is at its highest, such as during winter evenings when households across the country switch their heating on. The use of renewable energy generation alone to completely decarbonise these peak demand times is not always possible, as the wind doesn't always blow and the sun doesn't always shine. As a result, encouraging energy flexibility from those connected to the grid, by reducing, increasing or shifting the time of energy use, will become vital.

Energy use in homes currently accounts for 14% of the UK's total greenhouse gas emissions (1). Decarbonising homes through low-carbon technologies such as solar PV can ease energy poverty and reduce energy bills and carbon emissions. However, there has been little recognition for the role that homes can play in supporting the whole energy system through flexibility. This report considers the extent that domestic solar and battery storage systems help to balance the grid.

It provides in-depth insight into the consumer and system benefits of four generations of smart home. Each stage features the addition of a smart energy technology, such as solar PV, battery storage and intelligent controls that can respond to the energy needs of the household and the wider energy system. We also evaluate the household benefits of using solar PV, and battery storage to decarbonise and reduce energy bills.

We also look at the ability for homes to be smart and flexible in their energy use to support the wider electricity system. One particular type of home flexibility is analysed in depth: peak shaving, which is the avoidance of electricity use at peak demand times to reduce grid stress. To deliver system resilience and flexibility benefits, the report projects the need for up to 4.4million smart solar homes in the UK, a number consistent with the level of deployment required by 2035 to achieve net zero (2,3).

Achieving 4.4 million smart solar homes would not only deliver significant carbon reductions, energy bill savings and reduced fuel poverty for the people who live in them, but also the flexibility services and improved system resilience to enable higher levels of solar and wind generation onto the grid.

Key findings and Recommendations

Our aim is for these evidence-based insights to accelerate the adoption of smart homes, by encouraging the development of a supportive policy agenda. The report examines the following Generations of smart homes:

Generation 0
Basic: representing the average UK home today, without any form of low-carbon technology, smart controls or high energy efficiency measures.

Generation 1
Solar Homes: with solar PV installed.

Generation 2
Solar and Storage Homes: with solar PV and battery storage installed to maximise household benefits.

Generation 3
Smart Solar and Storage Homes: with solar PV, battery storage, and intelligent controls to support the grid and benefit the home in response to price signals (as set to the households' preferences).

Generation 4
Ultra-Flexible: homes with energy efficiency measures, electrified heating, and EVs installed alongside solar PV, battery storage, and intelligent controls, similarly set to automatically balance self-consumption with peak shaving.

KEY FINDINGS

1. 4.4million Generation 3 "Smart Solar and Storage" homes would eliminate the evening peak demand on a typical winter's day,
providing 12GW of energy storage capacity, which would offer approximately 40GWh of system balancing dispatch
2. Generation 3 homes can reduce consumption at peak demand times by 97% annually. Over winter months, as much as 80% of peak shaving ability could come from smart off-peak charging
3. Over 80% of a home's annual electricity use could come from low carbon sources when equipped with solar PV and battery storage, providing high levels of energy independence, substantial electricity bill savings, and carbon emission reductions
4. Generation 3 homes with a 20kWh battery installed can enable the home to come off grid all day or provide additional revenue-generating flexibility services
5. Homes with solar, battery storage and intelligent controls can offset the additional electricity demand that results from equipping homes with electric heating and EVs
6. Generation 3 homes in 2035 could reduce carbon emissions by 68% from self-consumption, peak shaving and charging their batteries at times of surplus renewable generation

KEY RECOMMENDATIONS

1. Improve the affordability of smart home technology by reducing the upfront cost. Financial measures such as zero interest loans, reduced or zero-rated VAT and grants should be made available to consumers
2. There must be strong standards and protections accompanying smart home technology for consumers and the grid
3. Opportunities for consumer flexibility must be maximised through: smart home education, a competitive smart tariff market with fully functional metering in place, evolving and accessible flexibility markets, a joint government and regulator smart homes consultation and ensured interoperability and ease of use for consumers
4. All new build developments should be smart homes. Building regulations must be set to incentivise onsite solar generation and energy storage, with an underlying Standard Assessment Procedure (SAP) methodology that keeps pace with advancing technology
5. Long term commitments to decarbonisation and flexibility must be made through RIIO2
6. The value of smart home properties must be reflected in green mortgages and house prices

Glossary

Aggregator: An aggregator can bring together numerous small assets to allow them to transact collectively in larger markets than they would otherwise have been able to (15). Aggregators enable homes to participate in flexibility markets through using available generation, storage, or demand side response. Often aggregators are independent from a home's existing energy supplier; independent aggregators include Powervault, Moixa and Sonnen.

Battery Arbitrage: Where the battery is charged up from grid-supplied electricity when tariff prices are cheapest (indicating there is plenty of generation). This stored electricity can then be used at a later point when power prices are high, so as to avoid using grid-supplied electricity in the home.

Battery Storage: A type of rechargeable energy storage. Lithium ion batteries are commonly seen in EVs and used in homes alongside solar PV. Lithium ion batteries typically have a long lifetime of at least ten years and are efficient, simple to use and compact. Which? members typically paid between £4,000 and £7,000 for their battery storage system (18).

Distribution Network Operator (DNO): DNOs are responsible for distributing electricity. DNOs own and operate the system of cables that bring electricity from the transmission network into local areas and to homes and businesses. There are six DNOs spread across the UK.

Demand turnup: Where customers increase their electricity consumption, for example, by charging their batteries, at times of excess generation.

Electrification: The switch from fuels such as gas and petrol to electricity in areas such as heating and transport.

Energy Storage: Energy storage allows for any excess solar generation to be stored and used later, reducing the amount of solar power being exported back to the grid. There are various types of energy storage used in homes, the most common being lithium-ion and heat batteries (water tanks and thermal stores).

Electric Vehicles (EVs): EVs are vehicles that have an onboard rechargeable battery using electricity, for example, from the grid or solar PV generation to power the engine (20).

Export: Export refers to any power that is provided to the grid, such as excess solar generation not used by the home or stored in a battery.

Flexibility (services): Flexibility is defined as modifying generation and/or consumption patterns in reaction to an external signal, such as a change in price to provide a service within the energy system (11).

Heat Pumps: Heat pumps take energy from a relatively low temperature source and forces that heat to a higher temperature making it more useful. Sources of heat include the ground, water and air (19).

Intelligent Controls: These enable a household to set preferences to automatically control time of energy use, where electricity is diverted to – for example, into battery storage, EV or general use and the time of export.

Net Zero: Net zero means that any emissions produced are balanced by the equivalent amount of emissions being taken out of the atmosphere. Achieving net zero will require rapidly reducing the amount of emissions we produce and, importantly, also offsetting any that remain.

Off-grid: Buildings that are independent from and not reliant on the grid for electricity.

Peak demand: Electricity demand is not steady throughout each day; there are peaks and troughs. Peak demand times are when electricity use is at its highest, typically in the evenings when most people return from work and power their homes. The typical GB peak demand time is 5pm-8pm on weekdays in winter (8,9).

Peak Shaving: Peak shaving refers to levelling out peaks in electricity use (12).

Price Signals: The rise and fall of the cost of electricity, these indicate when to adjust energy use and the optimal times to provide flexibility services.

Self-Consumption: Where solar energy generation is used onsite, such as a home with solar PV installed using the power generated for its electricity use or to charge an EV or battery instead of exporting it back to the grid.

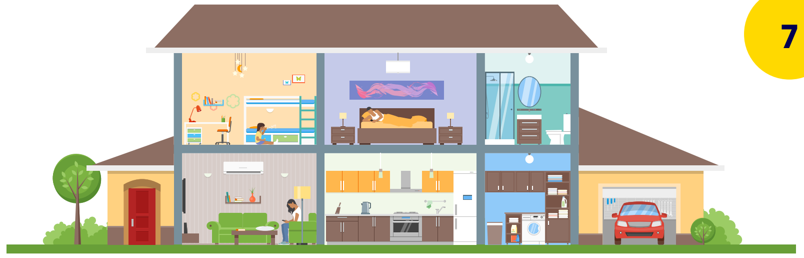
Solar PV: Solar PV converts energy from the sun into electricity, reducing electricity bills through self-consumption. Solar PV has been a reliable technology with a service lifespan of over 25 years. The average household installation is 3.4kWp in size, typically between 12-16 panels, with an average cost of £5000.

Supplier: A company that supplies electricity and gas to homes and businesses.

The Grid: The interconnected network infrastructure that distributes and transports electricity.

Variability: The variable nature of renewables such as solar and wind, where generation levels will vary from one day to the next depending on the levels of sunlight and windspeed, among other factors.

Introduction



This report reveals the vital contribution homes can make in the journey to net zero. By using real world data to identify, analyse, and compare four generations of smart homes with the average UK home today, it demonstrates the numerous consumer and system-wide benefits of reducing energy poverty, cutting carbon and supporting the power system.

Over the past decade, the UK has deployed more than 13.5GW of solar PV, yet more than four times this is needed by 2035 to accommodate the increased electricity demand that will result from decarbonising heat, transport and the wider economy (4, 2).

Renewable power generation, such as solar PV and wind power depends on weather conditions, and this variability, accompanied by the growing electrification of energy use, means that it is becoming increasingly challenging to balance the power grid. Imbalances are caused when demand, such as the electricity used by homes and businesses, does not match supply. Grid imbalances are managed by network operators, who use a range of options to respond to any immediate or anticipated issues.

As a result, it is becoming more valuable for entities connected to the grid, such as homes and businesses, to be flexible with their energy use, by shifting, turning up or down their demand and/or when they export energy back to the grid. The transition to a smarter and more flexible energy system, where supply and demand can respond more efficiently to the system's needs, will be essential to support cost-effective decarbonisation.

The emergence of intelligent home controls, enables homes to become semi-autonomous. Intelligent controls allow homes to automatically respond to price signals, such as the prices on time of use energy tariffs and adjust behaviour accordingly. One application of intelligent controls uses a solar PV and battery storage system to automatically peak shave – where a home reduces its use of grid electricity in response to signals that the grid is stressed, such as at times of peak demand. It is often then that the carbon intensity of the grid is highest, meaning that by reducing electricity use at peak demand times this type of smart home can support the system, reducing stress and dependence on fossil fuels.

The idea of using smart homes to support the grid is not new, but mass adoption of smart energy technologies has so far been limited. Early adopters of solar PV were not financially rewarded through the Feed-in Tariff (FiT) scheme to shift their energy use or export power at beneficial times for the system. Battery storage has only recently begun to make economic sense.

Few suppliers currently offer dynamic 'time-of-use tariffs' (TOUTs), where households can benefit from lower electricity prices for importing from the grid at particular times and are incentivised to avoid importing from the grid by higher electricity prices at others. The high and impractical levels of management involved deters many households from switching to TOUTs. Similarly, other financial incentives, such as flexibility tenders run by local network operators, are currently limited. This means there are few homes with solar PV and battery storage systems that currently maximise their response relative to the grid needs.

This report shows why and how the roll-out of smart solar homes can benefit households and support the electricity system on the journey to net zero.

Why We Need Smart Homes

2019 saw the UK become the first major economy to pass net zero emissions legislation.

Seen as central to achieving net zero, Government policy has started the transition to electric vehicles (EVs) and heat pumps. Both will drive electricity demand up, increasing the need for additional renewable generation. Peak demand levels, when electricity use is at its highest in the day, will also increase. All of these factors will place stress on the UK electricity system. As a result, the network operators who are responsible for balancing the grid will face localised challenges, such as lots of EVs being plugged in to charge at the same time in commuter areas, and national challenges, such as anticipated low levels of demand and high levels of generation over a sunny and windy bank holiday.

Such challenges can be addressed by incentivising throughout the power system. Flexibility includes shifting, increasing, or decreasing electricity use, storage, or exporting back to the grid at certain times. Encouraging widespread flexibility can defer costly grid reinforcements, in turn benefiting energy bills as grid upgrade costs are passed through to consumers. Increased flexibility will also enable new renewables to connect to the grid and even prevent renewable generators from being turned off or turned down when there is too much generation at times of low demand. Flexibility can further decrease carbon emissions by reducing the need to use high-carbon fossil-fuel generators at peak times and is critical in helping to prevent unintentional outages, disconnections or uneccessary investment in expensive infrastructure.

The number of ways to help balance the grid through flexibility is rising, reflecting the growing importance and market value of flexibility relative to the cost of alternatives, such as upgrading or reinforcing grid infrastructure. However, not all entities providing flexibility services are low-carbon. For instance, gas power stations are often used for flexibility yet they are carbon intensive, polluting, and reduce the UK's energy independence. Alternatively, the Government could incentivise and reward the adoption of flexibility from low-carbon smart homes. This could help balance the electricity grid with low-carbon technologies, bring more renewables to the system, and reduce the costs of running our electricity networks. One estimate indicates the cost savings at £6.9bn. (14)

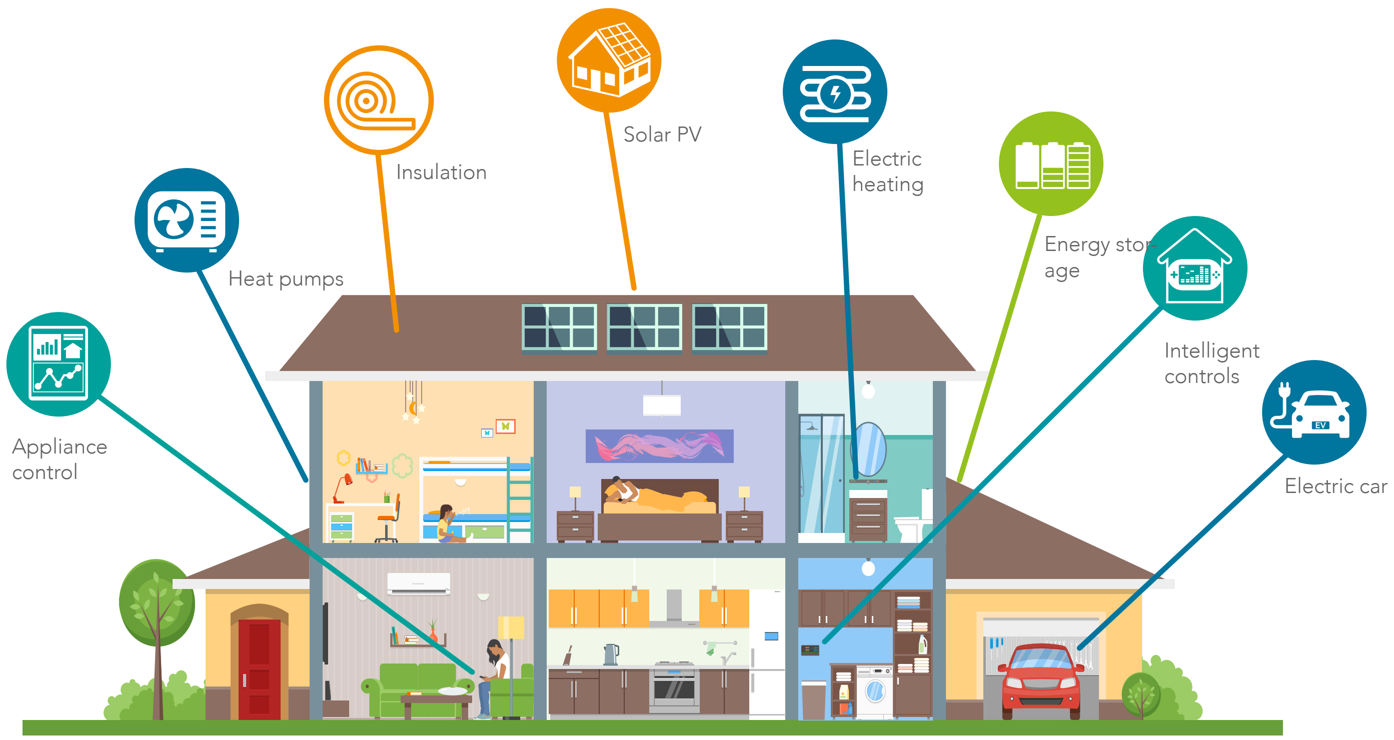
While it's clear that households could play an important active role in creating a more flexible electricity grid, currently only a small minority of homes provide flexibility through TOUTs or by participating in network-run local flexibility tenders due to policy and regulatory barriers.

What is Net Zero?

Net zero means that any emissions produced must be balanced by equivalent emissions being taken out of the atmosphere. Achieving a net zero economy by 2050 will require rapidly reducing the amount of emissions we produce and offsetting any that remain. To reduce our emissions, ramping up renewable energy generation is key. By 2035 it is estimated that 54GW of solar will need to be installed. The Solar Trade Association projects domestic solar could make up 15GW of this, equivalent to 4.4 million homes (7,3).

Barriers to Smart Homes

- **The upfront cost of smart home technology:** the cost of solar PV and battery storage can act as a major barrier to those wanting to install them, and developers seeking to build new smart homes.
- **Limited accessibility:** markets for flexibility services are only just emerging, so there are limited options currently available to homes. To date, the successful participation of smart homes in network-run flexibility tenders has been limited to those that are part of an aggregator's portfolio (often requiring the aggregators preferred type of system). It should also be recognised that the aggregation market currently has a relatively limited presence in the UK, which indicates there are constraints to this approach. Other types of flexibility, such as TOUTs, also have barriers to entry.
- **Limited incentives:** while markets for flexibility are developing, the financial incentives driving participation are currently limited and are widely perceived as being a nice-to-have rather than a key driver of investment.
- **Consumer understanding:** many households have limited engagement with their energy use, so there is low understanding of how their homes can contribute to achieving net zero and why it is important.



The Smart Solar Home Journey

The journey to a smart solar home can be understood by imagining four generations of progressively smarter homes. Most of the UK's homes are currently Generation 0 Basic. Close to a million have solar PV installed, forming Generation 1 (16). Tens of thousands are estimated to be Generation 2 homes, featuring solar PV and battery storage. However, just a fraction of these are Generation 3 smart homes, which feature intelligent controls to manage the system, and even smaller is the number of Generation 4 Ultra-Flexible homes that boast heat pumps, EVs and maximum energy efficiency.

Generation 0 (G0) Basic

Representing the vast majority of the 29 million typical homes across the UK currently without intelligent controls, renewables, or significant energy efficiency measures (1). This generation includes the 16.5 million homes that have had a smart or advanced meter installed (17). Whilst smart meters are an important step towards a smart electricity system, in their current form they do not support the grid.

Generation 1 (G1) Solar Homes

Solar PV converts energy from the sun into electricity. It is a reliable technology with a typical lifespan of over 25 years. The average household installation is 3.4kWp in size, typically 12-16 panels, with an average cost of £5000. Homeowners with solar PV installed enjoy lower energy bills as they can generate a portion of their own electricity.

The majority of the UK's rooftop solar arrays were installed under the Feed in Tariff (FiT) subsidy scheme, which was closed in 2019. These homes also continue to benefit from subsidy payments for the power they generate and export to the grid. The scheme was not designed to incentivise self-consumption nor flexibility.

Generation 2 (G2) Solar and Storage Homes

Energy storage allows for any excess solar generation, i.e. what is not needed at that time in the home, to be stored and used later, maximising self-consumption of the electricity generated. There are many different types of energy storage used in homes, and this report focuses on increasingly common lithium-ion batteries. These typically have a lifetime of at least 10-15 years and are efficient, compact and easy to use. Members of consumer group Which? typically paid between £4,000 and £7,000 for their battery storage system (18).

Now the FiT subsidy scheme has ended, households installing solar benefit most from maximising their self-consumption; this increases electricity bill savings by reducing electricity imports from the grid. As a result, it is estimated that battery storage is being installed alongside about half of all new solar PV installations. This technology is particularly suited to homes where occupants are out most of the day when most of the solar power is generated.

Generation 3 (G3) Smart Solar and Storage Homes

Intelligent controls can be used to automatically manage electricity use to respond to price signals. They enable the household to set preferences to control time of use, where the electricity is diverted (e.g. into battery storage, EV charging or general use) and the time of export. Some battery storage devices have automatic controls embedded, while other systems require the addition of intelligent controls.

The addition of intelligent controls enables households to balance self-consumption with the delivery of flexibility services, such as by automatically responding to TOU price signals that incentivise time of use and peak shaving. Intelligent controls also enable so-called battery arbitrage, which involves significantly increasing a home's ability to peak shave.

What is Battery Arbitrage?

An arbitrage battery is charged up from the grid when the tariff is cheapest. This stored electricity can then be used at a later point when power prices are high, such as during peak demand times.

Generation 4 (G4) Ultra-Flexible

Heat pumps draw heat from a cool space and release it into a warmer one. Sources of heat include the ground, water, or air (19). Electric vehicles are powered by electricity drawn from a rechargeable battery (20).

It is projected that Generation 4 homes no longer use gas, are more energy efficient, have electrified heating and EVs to go alongside the solar PV, battery storage and intelligent controls. These enable decarbonisation across the home, alongside the potential of providing additional flexibility via vehicle to grid. In coming years, the energy system will require highly flexible energy users. As with Generation 3 homes, intelligent controls can connect a combination of technologies to balance self-consumption with price signal response that incentivises time of use and peak shaving.

Smarter Homes Today

Generation 1: Beginning the Smart Home Journey
Generation 2: The Real-World Performance of Solar & Storage Homes
Generation 3: The Potential Performance of Smart Solar Homes

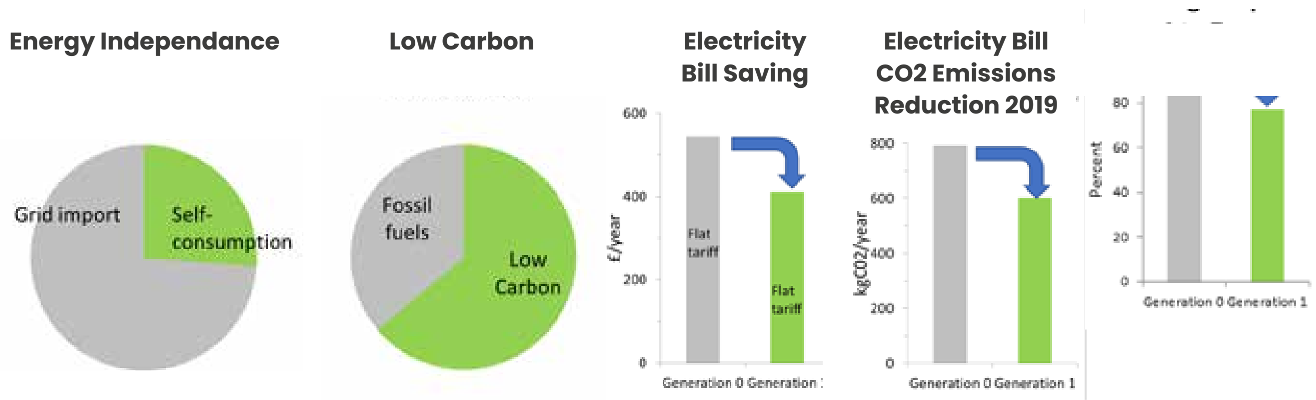
Generation 1: Beginning the Smart Home Journey

Starting from scratch

Generation 0 "Basic" homes are 100% dependent on the grid with annual electricity bills of £544. 51% of their electricity use comes from low-carbon sources. Their CO2 emissions come in at 791kgCO2.

The FiT subsidy scheme, which ran from 2008 to 2019, incentivised the installation of solar PV on almost a million homes across the UK. The FiT demonstrated the powerful impact policy can have on Britain's electricity consumers and has provided a strong foundation for home flexibility. It is important to understand what benefits these homes can currently contribute, in order to consider how homes should evolve.

Figure 3: Generation 1 Smart Homes Dashboard



Generating 26% of own electricity needs

Over 64% of electricity from low carbon sources

Annual bill reduced from £544 to £411

Reduced from 791 to 602 kgC02/year

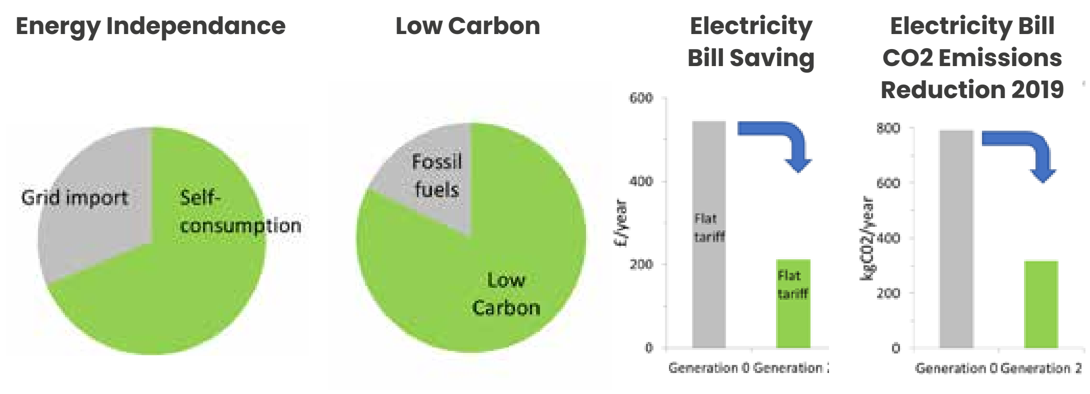
Installing an average 3.4kWp of solar PV increases energy independence by 26% on average. As a result, electricity bills are cut by an average £133 and the proportion of power obtained by low carbon sources increases by 13%. The overall carbon emissions of the house are cut by 24%.

Now, with a subsidy scheme no longer in place, many households are considering how to make the most of the solar they generate. Both existing FiT homes and those with new solar installations are increasingly progressing to the next generation by installing battery storage.

Generation 2: The real-world performance of Solar & Storage Homes

The addition of a 10kWh battery improves the homes energy independence by an additional 43%, and increases the proportion of electricity coming from low-carbon sources by a further 18% – a percentage in line with the progress needed to achieve the UK Government's 2050 net zero target, demonstrating how a home with solar PV and battery storage can already meaningfully contribute towards the UK's carbon targets. Over the year, electricity bills are reduced by a further £199 and carbon emissions from the home fall by an additional 36%.

Figure 4: Generation 2 Smart Homes Dashboard



Generating 69% of own electricity needs

Over 82% of electricity from low carbon sources

Annual bill reduced from £544 to £212

Reduced from 791 to 317 kgC02/year

Dashboard Metrics

For each generation of home, several key indicators are presented in comparison with the basic home. These indicators are:

Energy Independence (%/year): the annual percentage of a home's total electricity demand that is derived from on-site solar generation, compared to the percentage electricity imported from the grid.

Low Carbon (%/year): the annual percentage of a home's electricity demand that comes from low carbon sources. This percentage is the proportion of self-consumed solar generation combined with the proportion of grid imported electricity which is also low carbon (in 2019, the low carbon proportion of grid electricity was, on average, 51%).

Electricity Bill Savings (£/year): annual electricity bill savings are calculated through the avoided costs of importing grid electricity. Generations were placed on a flat, or time of use, tariff, depending on whether the generation could respond to price signals. The flat tariff was set to 15p for all tariff periods.

CO2 Emission Reductions (2019): The reduction in carbon emissions that is achieved across the year, based on the carbon intensity of 2019. This uses the dynamic 'average of power mix emission' factor as calculated by the National Grid carbon intensity calculator for 2019.

Average Import 4 to 7pm: This is the average power imported from the grid between 4 and 7pm (peak hours) for a typical home with an annual demand of 3400kWh/year (not to be confused with the ADMD for LV network planning).

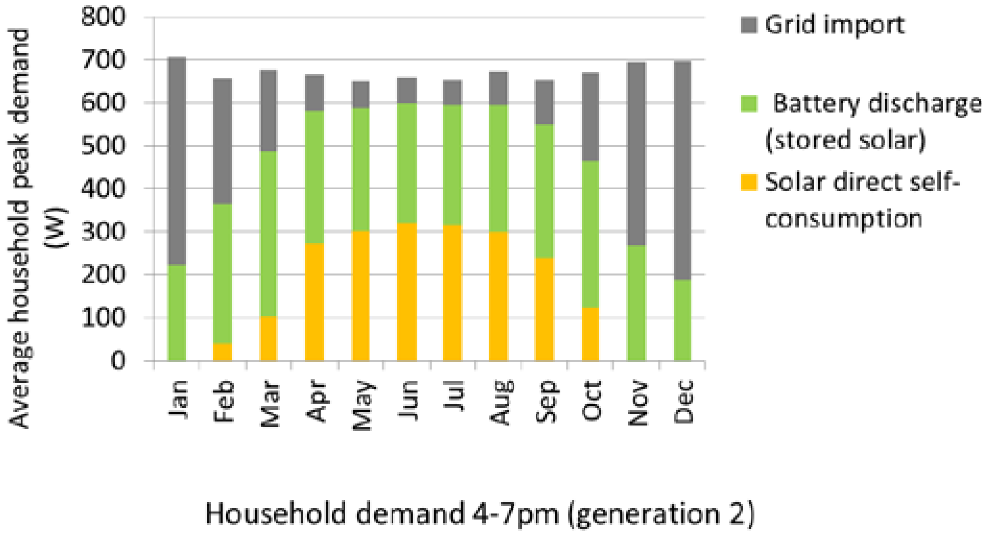
Peak Shaving Potential of Generation 2 Homes

In addition to the benefits achieved through self-consumption, G2 homes can also have a role in reducing grid stress by providing flexibility. Installing battery storage alongside solar PV allows homes to reduce the import of electricity from the grid at peak demand times (4pm-7pm). Over a year, G2 homes can reduce peak imports by almost 70%.

Figure 5 shows the average monthly peak demand of a typical home and the proportion of grid imports, direct self-consumption of solar generation and battery discharge of stored solar that the home uses to meet this peak demand. Grid imports are reduced across all months by the solar and storage system but particularly over May, June, July and August. During the summer, grid imports make up as little as 10% of the home's typical peak demand. However, the winter months show a different picture. G2 homes peak shave considerably less during the darker winter evenings when there is also higher peak demand. There is no direct self-consumption of solar generation during peak demand times in November, December and January. In these months, peak shaving completely relies on the battery discharging stored power generated outside peak times. Consequently, grid imports are much higher, exceeding 70% in December.

To achieve net zero, it will not be enough for smart homes to provide flexibility only in the summer. Energy flexibility will also be required at times of sub-optimal weather and high demand. For example, the 2018, Beast from the East, drove electricity demand up by 10%, with the evening peak demand reaching the highest it had been for three years (22). Electricity prices soared five times above the average for that quarter. Major energy users that could reduce consumption at times of high price volatility in the energy system were able to benefit financially (23). So, what can be done to enhance flexibility during winter?

Figure 5: Monthly Household Peak Shaving: Generation 2



Generation 3: The potential performance of Smart Solar Homes

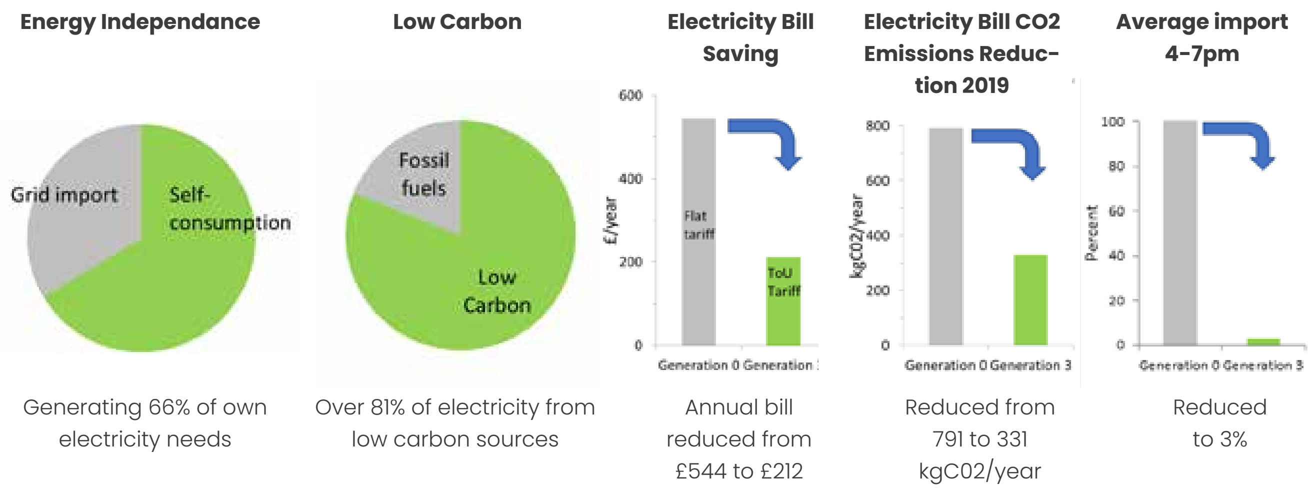
Generation 3 sees the addition of intelligent controls to the solar PV and battery storage system, which respond to price signals. The household's preferences are set to keep the same level of self-consumption as was achieved with Generation 2, whilst automatically responding to price signals on a three-tiered TOUT, enabling battery arbitrage (charging the battery during the night) and peak shaving. Although some homes across Europe are already using home flexibility for grid services, this is far from business as usual in the UK. Over this decade, the main value of G3 homes lies in their peak shaving contribution. By the 2030s, the potential for G3 homes to contribute to grid flexibility and cut carbon will be much greater due to wider access, opportunities and incentives for homes to respond more flexibly.

The G3 home can be expected to provide additional flexibility beyond the energy bill reduction typically achieved for G2 homes.

There are currently no signals to homeowners at times of high renewable generation that would allow G3 homes to intelligently reduce carbon emissions and increase their low carbon percentage above what G2 homes can achieve. However, this is expected to change as incentives for home flexibility become more available.

Similarly, the bill savings that result from G3 being placed on the TOUT would not result in increased savings compared to G2 on a flat tariff. As the tariff prices were based on an actual TOUT offered to homes, this may suggest current homeowner incentives to act flexibly may be insufficient compared to the benefits of self-consumption.

Figure 6: Generation 3 Smart Home Dashboard



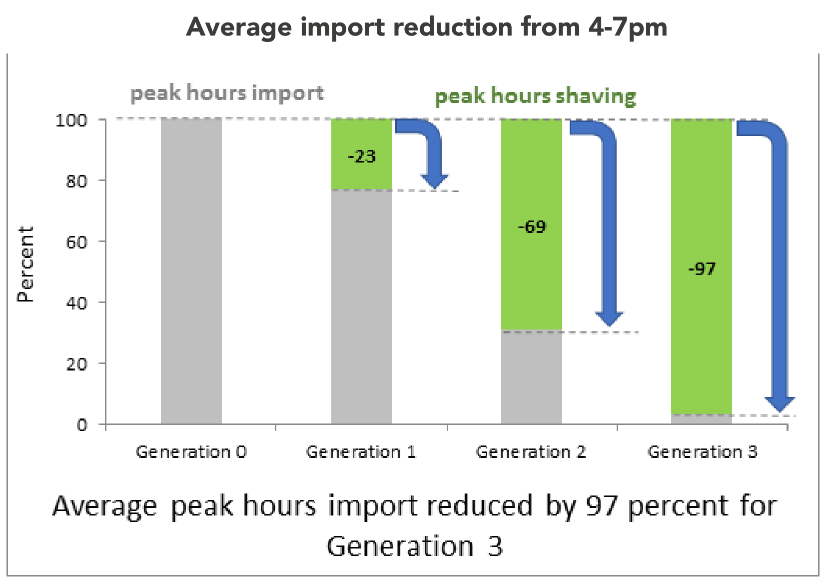
Intelligent Controls: Making batteries work smarter and harder

The household's preferences are set to respond to TOU price signals. Because of this, the battery is no longer simply charged with the excess solar energy generated. Now, in response to increasing and decreasing price signals, the battery is working more to arbitrage, charging from the grid during off-peak times to minimise the need for import during peak demand times later. Generation 3 homes's energy independence and low- carbon performances is marginally reduced as a result. Using intelligent controls to charge at night for peak shaving, while maintaining high self-consumption of the solar generation increases the cycling of the battery (the number of times the battery is charged and discharged). As each cycle of the battery results in small efficiency losses, there are slightly higher grid imports to compensate.

Peak Shaving Potential of Generation 3 Homes

Figure 7 shows the comparative reduction in average household peak demand of Generation 1-3 homes on a typical January day. G3 homes can actively reduce grid imports by 97% at peak times with intelligent TOU and battery arbitrage, in direct contrast to the reduced peak shaving, achieved passively by G1 and G2 homes, which simply make use of direct and stored solar generation during peak hours.

Figure 7: Peak Shaving Potential Generation 1-3



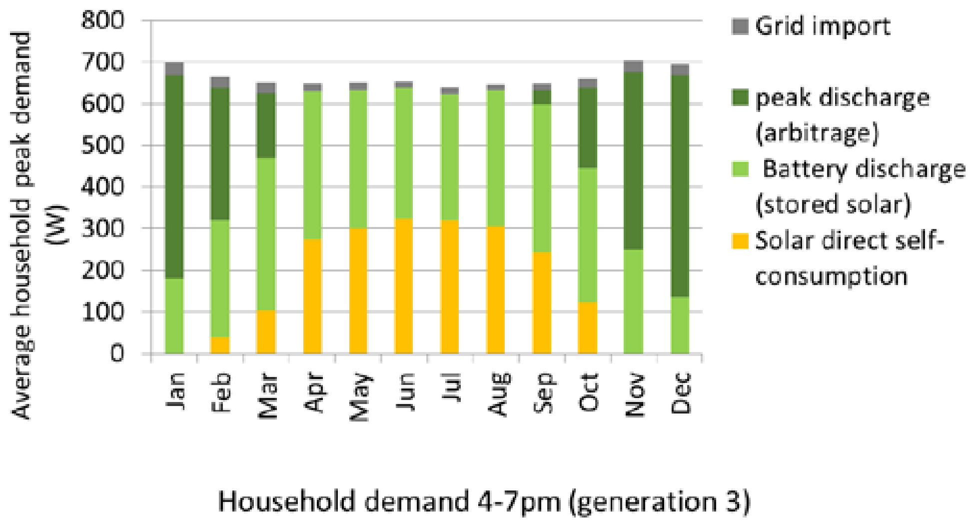
Compared to G2, peak shaving is achievable across the year with a G3 home. Figure 8 shows this spread on a monthly basis, with G3 homes contributing to peak shaving through a combination of direct self-consumption of solar generation, discharge of stored solar generation and
battery arbitrage.

Summer peak shaving is met almost entirely by solar power, either used directly or stored in the battery, until it is discharged during peak hours. There is a slight increase in peak shaving over the summer months from the discharge of stored solar PV in G3 homes compared to G2. This is because the intelligent controls intentionally reserve the solar generation to discharge during peak hours, minimising grid peak imports further compared to G2 homes.

Comparatively, arbitrage accounts for as much as 80% of peak shaving during winter months, when there is less solar generation. The batteries are mainly charged overnight during periods of low demand and discharged during peak times. The ability for homes to contribute so substantially to peak shaving during winter presents a valuable opportunity, with the potential to significantly improve system resilience - especially during more extreme weather conditions.

Key Finding: Annually, Generation 3 Smart Solar and Storage homes can peak shave by 97%. Over winter months, as much as 80% of peak shaving comes from smart off-peak charging

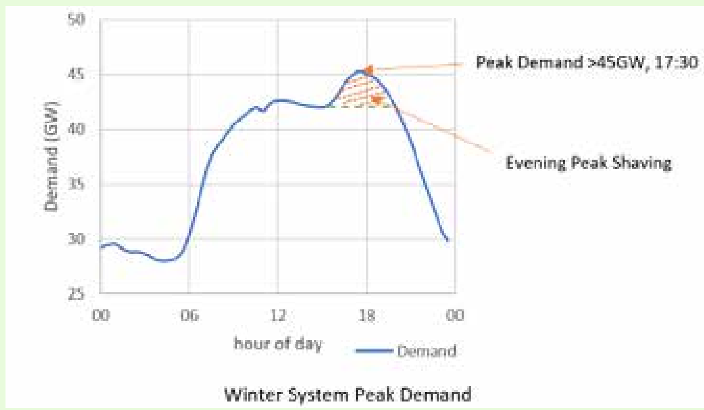
Figure 8: Monthly Household Peak Shaving: Generation 3



What is Peak Shaving?

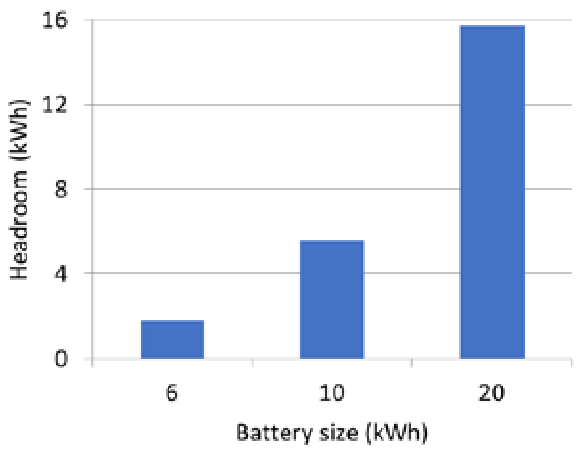
Peak shaving refers to levelling out peaks in electricity use (12). The goal of peak shaving is to balance what is already connected to the grid and reduce costs by removing the need to install more generators to supply during times of higher demand (13). Figure 1 shows the total electricity use across one day in winter 2019 in Great Britain. In the evening, roughly between 4pm and 7pm, there is a sudden, substantial increase in electricity use – peak demand. Peak shaving would level this peak to a level consistent with before 4pm, as indicated by the green dotted line. Importantly, peak shaving can reduce the need for additional (often high-carbon) generation, contributing to further decarbonisation. Peak shaving can be encouraged through price signals, such as those from a supplier providing a Time of Use Tariff (TOUT).

Figure 1: Peak Shaving



Pushing Generation 3 Further

Anticipating future flexibility opportunities, some households have reportedly equipped their homes with oversized batteries relative to what they need to meet their own energy demand. We considered the headroom capacity that 6kWh, 10kWh and 20kWh battery storage devices have - the capacity to provide additional services, while ensuring that self-consumption and peak shaving ability is not impacted. Smaller batteries such as the 6kWh have limited headroom capacity to provide flexibility beyond peak shaving and self-consumption.



Winter headroom capacity for different battery capacities

But, with 20kWh batteries, the home could potentially go completely off-grid all day. Homes could also provide demand turn-up, where is charged from the grid at times when there is excess generation. Alternatively, the battery storage could use excess stored electricity to export to the grid at times when there is not enough generation to meet demand. Our findings suggest an aggregator with one million 20kWh smart homes, in December and January, would have over 13GWh of headroom capacity and be able to deliver an additional 3.25GW of flexibility over four hours. That's roughly the same capacity as the existing pumped hydro storage resource in the UK.

As the number of days with surplus renewable generation grows, so too should the opportunity for households to participate in new revenue-generating grid support services, which remain at an early stage of development.

We are already seeing examples of innovation in this space. One energy supplier trialled paying homes to use electricity during certain hours to avoid renewable generation being curtailed over the 2020 May Bank Holiday weekend (24).

Households can also earn money for their exported electricity through the Smart Export Guarantee (25,26). There is currently only one genuinely smart export tariff, that tracks half hourly market prices and incentivises smart export. The supplier suggests that smart solar and storage homes could earn £436/year through this tariff, which is over 50% more than what could be earned on their flat tariff (27).

Flexibility could also be requested by a local network operator. In 2019, Moixa similarly secured the right to offer 50kW of flexibility from its network of 4.8kWh home batteries in one network area (29). The company initially introduced a flat £50 cashback scheme when households let them use their battery for flexibility services (30). Aggregators now also make payments based on the extent to which the battery is used for flexibility.

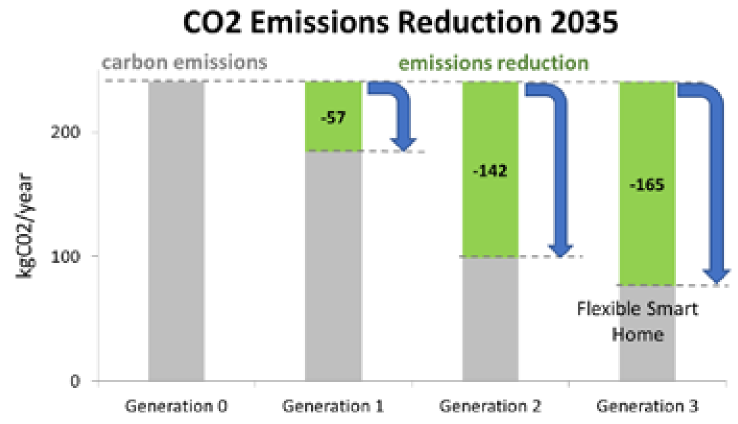
Key Finding: Beyond self-consumption and peak shaving, Generation 3 homes with a 20kWh battery installed have triple the headroom capacity that 10kWh batteries have, enabling the home to go off grid all day and/or provide additional revenue-generating flexibility services.

Potential Carbon Reductions Achievable in 2035

In the future, there will be many occasions when an excess of renewable electricity generation will be on the grid. Turning this generation off rather than using it limits the carbon reductions that it could contribute. G3 homes will be well-positioned to absorb this surplus alongside other types of storage installed on the system, such as pumped hydro storage and EV batteries. Based on industry estimations and official emission projections (31) it is expected that G3 homes along will produce further carbon savings by storing excess generation in batteries and using it when carbon is most intensive.

Figure 10 shows the carbon emission reductions possible across Generation 1-3 homes that can be expected by 2035.

Figure 10: 2035 CO2 Emissions Reduction Generation 1-3



Reduced from 241 to 99 kgC02/year for Generation 3

For G0 homes, emissions are expected to fall by almost 70% by 2035 compared to 2019. In one scenario with 89GW of wind and solar there was an estimated 9TWh of potential surplus renewable energy. Although some of this surplus will be taken up by electric heating and EVs. G3 homes are also able to charge their batteries on a share of surplus low-carbon energy and discharge their batteries at times of peak demand, achieving a further reduction in carbon emissions of 10%.

Key Finding: 2035 scenarios estimate that compared to basic homes, Generation 3 homes could reduce carbon emissions by 68% from self-consumption, peak shaving and charging their batteries at times of surplus renewables.

Looking Forward

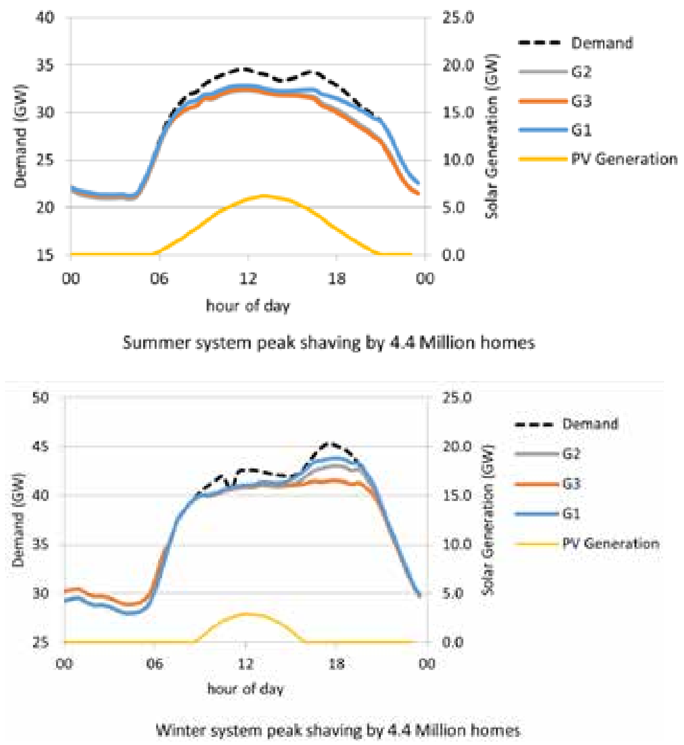
The Potential System Benefits

Alongside the benefits to individual households, the flexibility potential of smart homes is vital to the electricity system as a whole.

When scaled up across Generations 1-3, the purposeful smart strategy of peak shaving by G3 homes was over three times more effective when averaged over December and January (note: the following analysis does not include making use of any headroom capacity). Figure 11 shows GB's total system electricity demand on a typical summer and winter day, as shown by the black dotted line. Illustrated alongside this is the reduction in total electricity demand achieved from the aggregated impact of 4.4 million homes of Generation 1-3.

G3 homes can eliminate evening peak demand, regardless of whether a 6kWh, 10kWh, or 20kWh battery is used, consistently enabling roughly 3GW of peak shaving at times of highest grid stress.

Figure 11: System Summer and Winter Peak Shaving

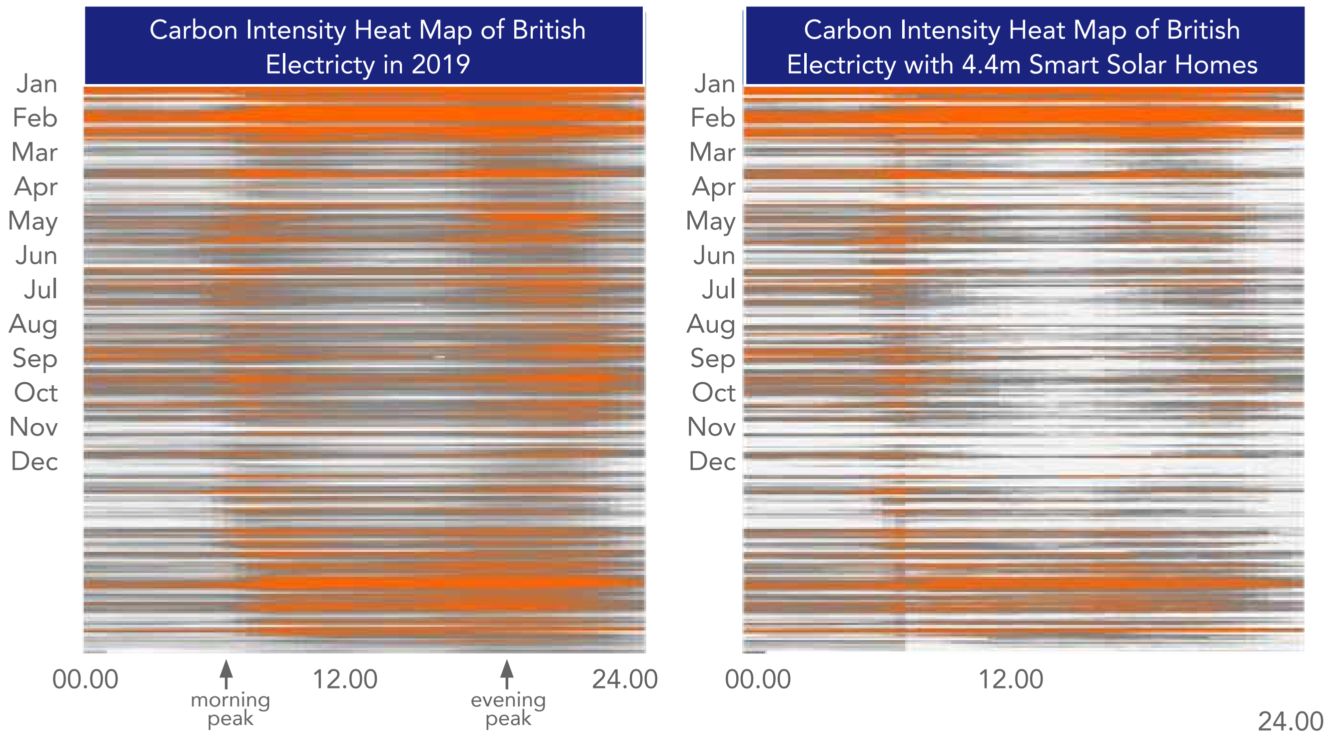


Key Finding: **4.4 million Generation 3 Smart Solar and Storage homes can achieve 3GW of peak shaving, which today is enough to eliminate the evening peak demand on a typical winter's day. The deliberate smart strategy of peak shaving by Generation 3 homes is over three times more effective, when averaged over January and December.**

The Potential Carbon Benefits

However, the system benefits of smart homes are not limited to peak shaving. Shifting the behaviour of homes could also significantly affect carbon intensity at a national level. Figure 12 demonstrates this potential through carbon heat maps, which show dramatic carbon reductions with and without solar homes. The carbon heat map on the right shows the impact on grid carbon intensity that G3 homes calibrated to avoid peak import could achieve. Throughout evenings across the year, there is consistently less carbon — highlighting the decarbonisation that can be achieved as a result of optimal G3 behaviour.

Figure 12: Carbon Heat Map: the impact of smart homes



The carbon heat maps above show the carbon intensity of British electricity during different times and days throughout 2019. Along the Y-axis are the days of the year (beginning with January) and along the X-axis is the time of the day (beginning at 00:00am). Orange indicates when there is more carbon (i.e. more fossil fuels) on the grid. The carbon intensity of electricity is usually highest during the morning and evening peak and is also higher in the winter months when there is more electricity needed for heating and less renewable generation.

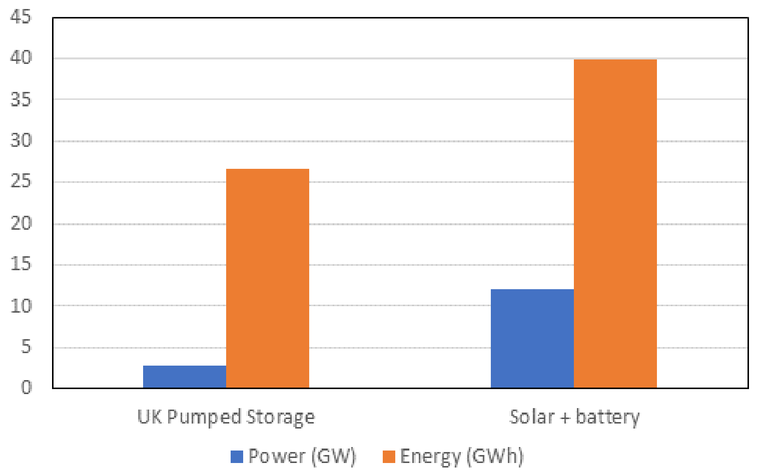
The Potential Contribution towards System Resilience

For over 50 years, pumped-storage hydroelectricity (PSH), or pumped hydro has been the main energy storage technology used to balance the electricity system. Today, PSH provides one of the few large-scale methods for storing low-carbon and low-cost electricity. Currently, the UK has a total PSH capacity of just under 3GW, which can deliver a maximum energy output of 30GWh before needing a recharge. However, when considering the 80GW of combined solar and wind power that could be required by 2030 (9), it is clear that the UK's PSH capacity falls far short of what is needed to balance any sudden drops in generation.

Furthermore, environmental concerns, high costs and uncertainties around investment returns for large centralised PSH assets in an evolving marketplace may hamper its adoption (34, 35, 36).

G3 homes can play a key role in future system balancing along with other energy storage technologies. Rapid growth of G3 smart homes to 4.4 million can deliver up to 12GW of additional capacity - more than four times that of the current PSH fleet. And with additional 'system balancing energy' of 10kWh per-household (the energy over and above that required for maximising self-consumption), smart solar and storage can offer around 40GWh of system balancing dispatch on top of the 27 GWh available from PSH (see figure 13). This shows the key future role that smart solar with storage can play as part of a truly flexible, decarbonised electricity system.

Figure 13: UK Pumped Storage Hydro v. 4.4million Generation 3 homes with 10kWh additional capacity



The rapid response time of domestic solar PV battery storage systems means they can react swiftly to electricity supply issues. Modern solar PV and battery inverters offer frequency regulation response, similar to that usually provided by natural-gas-fired peaker plants. As such, Gen 3 homes will help avoid future repeats of widespread rolling blackouts, such as those that took place in August 2019. Unlike PSH, the distributed nature of domestic storage means that system resilience is 'bottom up', meaning valuable flexibility will be available at local levels and from homes upwards.

The August 2019 Blackout

In August 2019, the UK experienced its first significant blackout in over a decade, with more than 1.1million households left without power. Batteries played a significant role in restoring the system to safe voltage levels and far quicker than during the UK#s previous blackout (36).

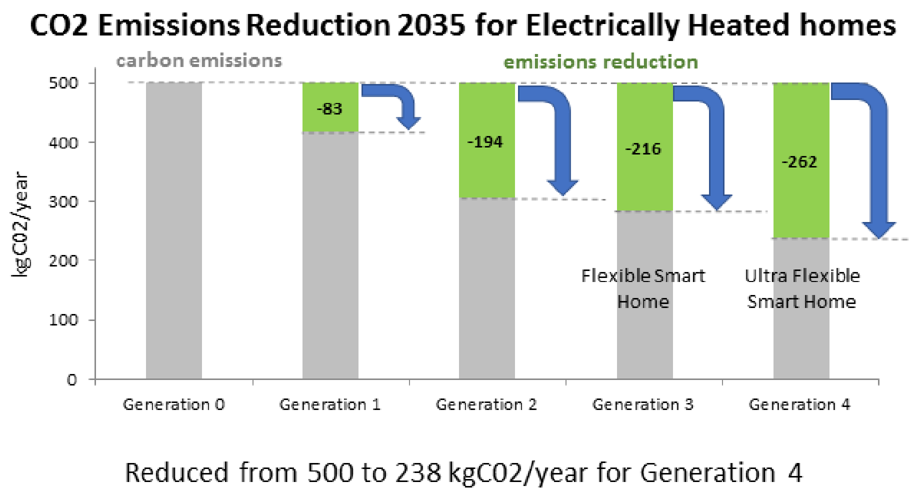
Generation 4 – Ultra-Flexible Homes

By 2030, domestic electricity demand looks set to increase substantially due to two main drivers: the electrification of heat and the electrification of private transport. The adoption of EVs is being supported by grants for charge points and a phase out of petrol cars from 2035. Heat pump uptake looks set to be incentivised under the Future Homes Standard, which proposes that by 2025 no new homes will be heated by gas, and the Clean Heat Grant. G3 dwellings will progress towards a fourth-generation smart home equipped with solar PV, battery, smart systems, EVs and heat pumps. EVs and heat pumps will not only create new demand but will significantly alter energy-use, potentially creating new morning peaks and night-time loads. Widespread adoption of smart-energy technologies will be critical to managing these new patterns.

Decarbonising Heat

Given a much lower carbon UK in 2035, Figure 14 shows the potential carbon reductions that can be achieved across Generation 1-4 homes, considering the energy efficiency measures that would be expected with each generation. This G4 solar smart home, which adds high energy efficiency measures and smart thermal storage to smart solar PV and battery storage, could reduce carbon emissions by an additional 9% compared to G3 homes. This provides a substantial further reduction considering the level of decarbonisation already achieved.

Figure 14: 2035 CO2 Emission Reduction Generation 1-4



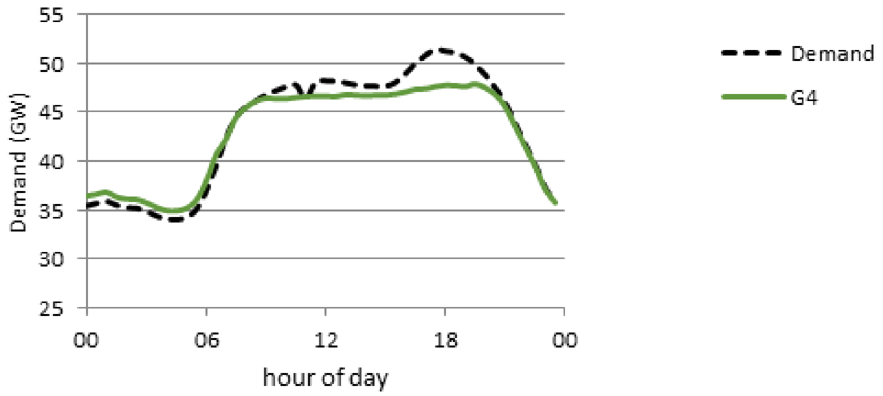
Decarbonising Transport

In addition to heat, the urgent need to decarbonise transport is widely recognised, with electric vehicle (EV) sales rising each year. The Government has already taken steps to incentivise smart charging by requiring all charge points to be smart capable. As such, EV owners can make use of TOUTs or electricity tariffs designed specifically for EVs to benefit the system and energy bills, without impacting their ability to make journeys. EVs will increase electricity demand and uptake could be concentrated in particular local communities, increasing network stress in certain areas. Charging 4.4 million EVs would require an additional average power capacity of 1.1GW and a maximum of 2.7GW, spread across 24 hours.

The Potential System Impact of Decarbonising Heat and Transport

Both EVs and electrified heat will change the energy demand profile of households considerably. Figure 15 shows the winter 24-hour period for total system demand (black dotted line), alongside the total demand reductions that 4.4million Generation 1-3 homes could achieve. The additional demand and time of use resulting from electrifying heat and transport has been applied to a new demand profile for Generation 4. By using smart charging for the EV, as steered by Government policy, peak import can be avoided. As a result, 3.7kW would be added to household demand which, across off-peak periods of 4-6 hours, would lead to an increase of 1.2kW per dwelling. Research at UCL and Loughborough University indicates that heat pumps create an additional maximum demand of 1.7kW per dwelling, with a 1.3kW increase occurring during peak demand times. In theory, this could an important be mitigated using battery arbitrage (38).

Figure 15: Generation 4 Estimated Additional Demand



Future Winter demand profile with heat and EV loads with peak shaving by Generation 4 homes

The potential benefits offered by smart homes to the household and wider electricity system are significant, including improved carbon emission reductions, bill savings, substantial peak shaving potential, additional flexibility services and bottom-up system resilience. However, tackling the remaining barriers such as upfront costs and often tricky to navigate regulations is imperative to realising the full potential of smart homes and their contribution to achieving net zero.

Conclusion

The main purpose of this report has been to highlight the many ways in which solar, energy storage and smart controls can accelerate Britain's transition to a net-zero carbon economy. Anyone looking to improve their home can be confident that installing these technologies will reduce energy bills, cut personal carbon emissions and increase their home's resilience. What this report also shows is that increasing the number of smart solar homes across the country creates an untapped potential for them to help the whole electricity system.

At a system level, millions of smart homes spread across the UK have the potential to flatten peak demand on the grid. Smart homes with larger storage systems can provide additional flexibility services to the grid without affecting their self-consumption and peak shaving ability. Looking to 2035, this could lead to further carbon reductions as surplus periods of renewable generation become more frequent. Smart energy technologies also have the potential to mitigate some of the impact of heat pumps and EVs on the grid and the bottom-up nature of smart home flexibility could further enhance the resilience of the UK's electricity system.

This flexibility potential will undoubtedly grow in importance. Already forward-thinking solar installation businesses are starting to engage homeowners about the potential for smart homes in the UK and their contribution to a zero-carbon future. The policy recommendations below are a summary of what the industry believes is necessary to unlock the potential highlighted in this report. They are drawn from a series of more detailed responses to government consultations, industry working group discussions and engagement with other stakeholders, including academics and policymakers. Governmental and Regulatory commitment to net zero must be translated into swift and meaningful action to help incentivise smart home flexibility and establish appropriate standards and protections, in the property market.

Solar power represents the first step on the journey toward truly low-carbon homes. A continued mass adoption of smart energy technologies in the home can cut domestic carbon emissions substantially, and reduce the cost of running the UK's electricity system. Now is the time to accelerate this opportunity.

About Us

As an established trade association working for and representing the entire solar and energy storage value chain, Solar Energy UK represents a thriving member-led community of over 240 businesses and associates, including installers, manufacturers, distributors, large-scale developers, investors, and law firms.

Our underlying ethos has remained the same since our foundation in 1978 – to be a powerful voice for our members by catalysing their collective strengths to build a clean energy system for everyone's benefit.

Our mission is to empower the UK solar transformation.

Together with our members, we are paving the way for solar to deliver 40GW by 2030 by enabling a bigger and better solar industry.