CORNWALL INSIGHT

CREATING CLARITY

Domestic heat pump flexibility modelling

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2 Executive Summary

This report was prepared by Cornwall Insight and commissioned by Nesta with the aim of understanding the opportunities for heat pumps to respond flexibly to changes in electricity prices.

About the research

We have assessed the value that could be delivered to households in the short term (up to 2030), on an individual basis, using different tariff structures and comparing opportunities for financial savings when operating a heat pump flexibly. We established a baseline heat pump profile under each tariff structure (flat rate, pass-through, and tri-rate) where the heat pump was not used flexibly. Our comparative scenarios allowed the heat pump to respond to price signals by pre-heating the home and reducing consumption during periods of high-cost electricity. We also analysed the impact of introducing additional renewable technologies - solar PV and battery storage - to understand the impact on flexibility opportunities and electricity costs to the consumer.

Key findings from our modelling

1. Consumers can make savings when the heat pump is used flexibly on a pass-through and tri-rate tariff compared to a standard heat pump profile on a single rate tariff

Our modelling found average savings of £640-£750/year by operating a heat pump flexibly on a time of use tariff (pass-through[1] or tri-rate) compared to a single rate tariff where the heat pump is operated on a standard heat pump profile.

Under the modelled pass-through tariff, the flexible heat pump responds to price signals and avoids consuming electricity during higher cost periods. Typically, more flexibility is deployed in response to the pass-through price signal in the morning and evening when network charges are higher. To maintain a comfortable temperature in the house, pre-heating is undertaken during periods when electricity prices are lower, delivering savings of £750/year on average.

Under a tri-rate tariff, the price structure is known in advance, and the heat pump responds more predictably. The highest cost period occurs for three hours during weekday evenings, where the heat pump avoids consumption, effectively resulting in no heating being undertaken during these times. As with the pass-through tariff, pre-heating occurs to ensure a comfortable temperature is maintained. Our modelling found average savings of £640/year by operating the heat pump flexibly on a tri-rate tariff, compared to the single rate, standard heat pump profile. The tri-rate tariff provides lower savings, as there are fewer periods with higher prices compared to the pass-through tariff.

Consumers can make savings when flexing on pass-through and tri-rate tariffs compared to not flexing on these tariffs

Operating a heat pump flexibly under a pass-through or tri-rate tariff results in a greater saving than without flexing, with the pass-through tariff[2] providing slightly higher savings than the tri-rate, £84/year and at £82/year respectively compared to not flexing on the same tariff.

For comparison, flexing a heat pump whilst on a single-rate tariff results in a greater average annual cost of electricity. Under a single rate tariff, the additional electricity consumption required for pre-heating incurs higher electricity costs than running a standard heat pump profile (i.e. no flexibility), and the lack of price incentives means this translates to an additional £46/year on average across the 10-year modelled period.

[1] A pass-through tariff is used to describe a dynamic time of use tariff, which has a different price per unt of energy depending on the time of day

[2] The benefits of a pass-through tariff are highest when the future wholesale price of electricity is falling. If wholesale prices are on an upward trend, a single rate tariff may deliver a better annual price for consumers

However, we note that we would not expect a user to undertake flexibility under this tariff structure in reality, unless other incentives were provided. Modelling of this scenario has been undertaken for comparison purposes only.

2. Adding solar and battery storage assets further increases the overall savings

Adding solar PV and battery storage sees increased savings under pass-through and tri-rate tariffs compared to a house with a heat pump and no additional renewable technologies. We found £810/year average savings for a heat pump operating flexibly under a pass-through tariff with solar PV and battery storage, compared to the same assets, tariff and no flexibility undertaken by any installed technology. The savings rate reached >£1,000/year on average in the same scenario when the heat pump was not used flexibly, but the solar PV and battery storage were.

The same trends were seen under the pass-through tariff and tri-rate tariff structures – higher savings when the heat pump was not used flexibly. The total cost of electricity was lower for the pass-through tariff than the tri-rate tariff, reflecting the higher number of opportunities under the pass-through tariff to access higher and lower price signals.

Through the rest of this report, we will provide:

- An overview of our modelling approach in **Section 3**
- A detailed overview of our results in **Section 4**
- Our views on future considerations in the heat pump flexibility space in **Section 5**

3 Modelling approach and assumptions

In this section, we present the scenario building and modelling assumptions used to underpin our analysis, before focusing on the dynamics of flexing heat pumps.

We have modelled electricity wholesale, network and policy costs associated with operating a heat pump flexibly in response to price signals through a range of tariff structures over a ten year period from 2024. When electricity prices are higher, the heat pump responds by pre-heating the home at cheaper rates earlier in the day and maintaining a comfortable temperature, but avoiding running when electricity costs are higher costs. Alternatively, high costs are avoided through the use of self-generated and self-stored energy using installed solar PV and battery storage.

The savings achieved by engaging in flexibility are dictated by the scale of volumetric related charges in the electricity bill. Over time, we expect to see changes to the scale and volatility of different cost components influencing the savings available from flexing heat pump demand.

The majority of these savings come from the wholesale electricity purchase component, typically the most volatile and with price changes influenced by global and seasonal factors. Additional but relatively lower savings are also made in network costs, as well as a small amount on policy costs which are charged on a volumetric basis.

The results and subsequently inferred conclusions are representative of our projection of the future market conditions at the time of our modelling in Q124. Greater levels of intermittency in generation than expected in our modelling is likely to drive bigger extremes in the wholesale market price, creating bigger benefits for flexing. In contrast, a consistently rising wholesale price could position the single rate tariff as a cheaper option compared to a time of use tariff, although this would depend on a supplier's hedging strategy and risk management.

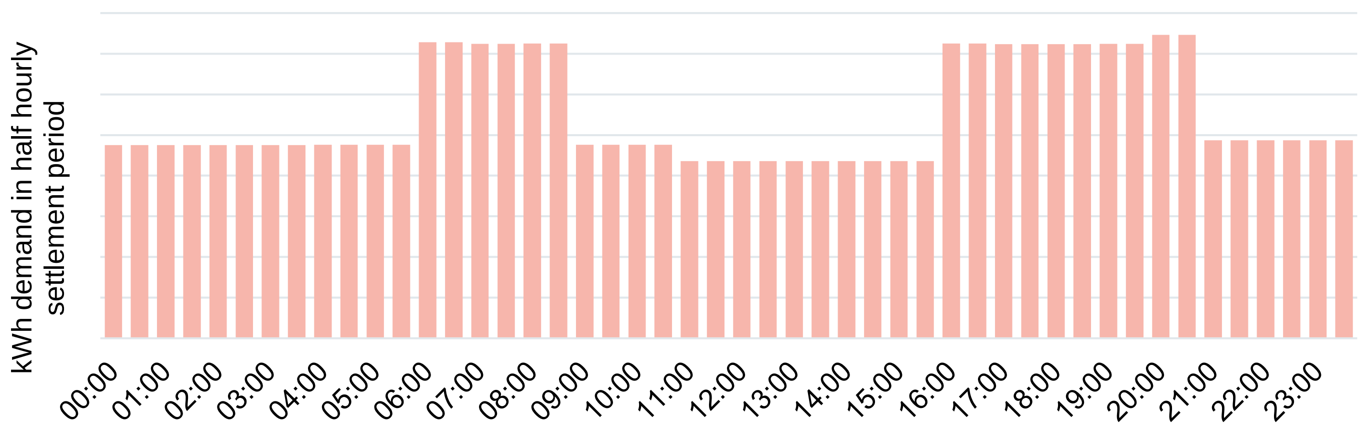
We note that the upfront costs of these renewable technologies (purchase and installation) were not considered as part of our modelling.

Scenario development

We have developed two heat pump scenarios for comparison: a standard demand heat pump (Figure 1), and a flexible heat pump which responds to price signals by preheating the home and reducing consumption during periods of high cost electricity. The flexible heat pump may have a different consumption profile each day, depending on the price signals it is responding to. (Figure 2)

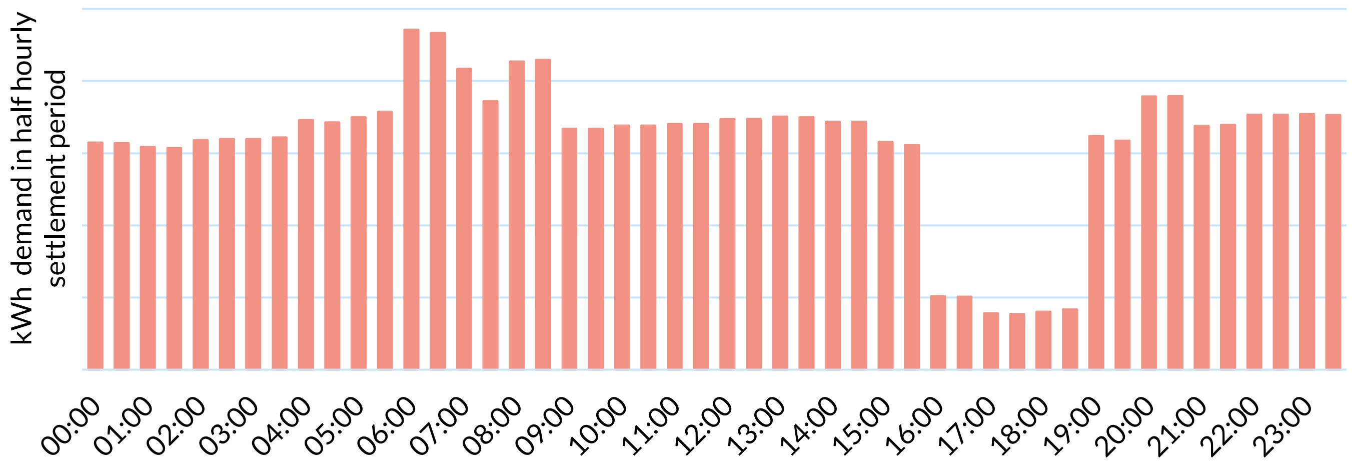
See the Assumptions section for further information on pre-heating and heat pump specifications.

Figure 1: Standard heat pump profile - example day



Source: Cornwall Insight

Figure 2: Flexible heat pump profile - example day

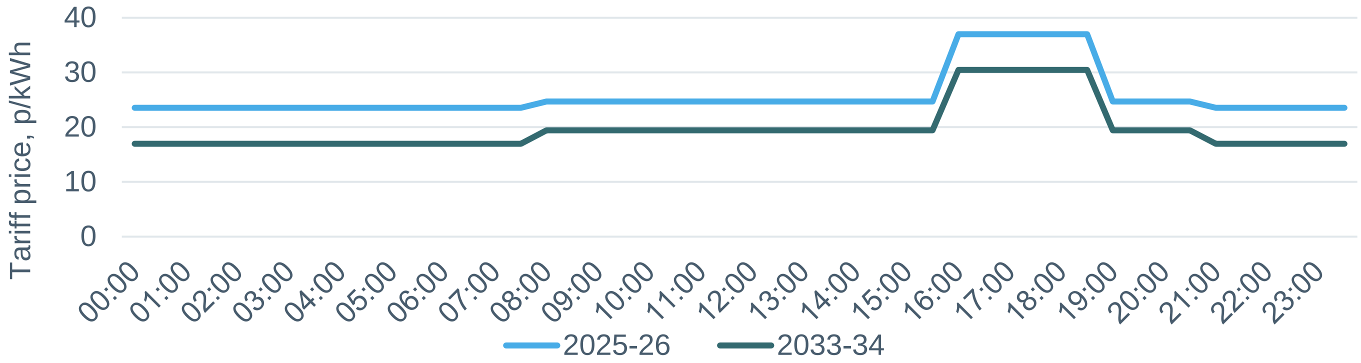


Source: Cornwall Insight

We developed three structures (single rate, pass-through, and tri-rate) for comparison. The tariffs include costs for the wholesale electricity, alongside other bill elements passed through by energy suppliers including costs to maintain and repair electricity networks, and policy costs (typically social and environmental policies):

- **Single rate tariff**: The customer pays a fixed standing charge and unit rate for their electricity based on their consumption. The rate changes annually, assuming electricity is purchased by the supplier at the start of each calendar year. This tariff structure does not consider the time of day at which electricity is consumed (i.e. not settled half-hourly)
  - This means price security for the customer against market volatility, but without flexibility incentives. Currently, the majority of household consumers are on a single rate tariff
  - We have assumed electricity is purchased at the start of each year. The price of this tariff would depend on a supplier's approach to risk management and ability to purchase energy in advance
- **Pass-through tariff**: Half-hourly costs for each bill element are provided directly to the household, meaning unit rates change each day with different prices for each half hour. Prices are set a day in advance
  - This tariff delivers clear price signals for flexibility response, but also passes on price risks with no fixed price security
- **Tri-rate tariff**: Bill elements are aggregated into three banded time-of-use periods that remain static across the timeframe analysed. The costs for each of these time periods is fixed for each financial year, to represent a 12-month fixed-term product structure (see Figure 3). This includes a peak rate (high price) between 16:00 and 19:00 each weekday, shoulder rates (shoulder hours typically fall between peak and off-peak rates and generally have intermediate pricing), and an off-peak rate (low price)
  - This structure provides clear and consistent signals for flexibility response, but does not pass through all price incentives

Figure 3: Tri-rate tariff prices during the day across two sample years, p/kWh



Source: Cornwall Insight

Figure 4 provides a breakdown of the 14 modelled scenarios, where three baselines (one for each tariff structure) were created in order to provide a benchmark against which we could compare the other 11 runs and understand any financial savings that may be available.

Figure 4: Model Run Configuration

Scenario number	Standard HP profile	Flexible HP profile	Single rate tariff	Pass-through tariff	Tri-rate tariff	Additional solar PV asset	Additional storage asset
Baseline	✓		✓				
Baseline	✓			✓			
Baseline	✓				✓		
1		✓	✓				
2		✓		✓			
3		✓			✓		
4		✓		✓		✓	
5		✓			✓	✓	
6	✓			✓		✓	✓
7	✓				✓	✓	✓
8		✓		✓		✓	✓
9		✓			✓	✓	✓
10	✓			✓			✓
11		✓		✓			✓

Assumptions

We have opted to use broadly median values for all technical factors, with the view to providing a reasonable baseline from which to make assumptions about how higher/lower specs would then also impact savings

- The consumer is assumed to use electricity for non-heat purposes aligned to a Profile Class 1[3] customer. Using Elexon's Profile Class 1, we have allocated Ofgem's Typical Domestic Consumption Value (TDCV)[4], the standard industry metric for typical domestic consumption, for a Medium consumer (2,700kWh) over the 17,520 half hour settlement periods of the year
- The savings achieved by engaging in flexibility are determined by the scale of volumetric-related charges in the electricity bill (i.e. where the fixed costs of the electricity is recovered proportionally to the amount used). Wholesale costs form the largest proportion of volumetric-related charges. We have used our in house long-term power market model (Benchmark Power Curve – Central scenario) to present our best view of wholesale electricity prices
- We assume that households have a 100amp import fuse, the maximum typically available for a domestic connection, which is single-phase. At 240 volts domestic supply, this gives 24kW of import capacity. This should enable the households (regarded individually) to import all electricity required for base consumption and heat pumps simultaneously
- The baseline electricity requirement peaks at up to 6.5kW
    - The heat pump for this model is assumed to have a capacity of 7kW
    - The battery storage technology for this modelling assumes the capacity to be 5kW, the duration to be 2-hour, and for the battery to be lithium-ion
    - The capacity of the solar PV technology is assumed to be 5KWp
- The flexibility mechanism[5] sees heat pumps shift energy demand to off-peak periods by turning up/down or on/off electricity use for a period of time, with a comfortable temperature maintained via thermal inertia or a dedicated thermal store
    - Space heating demand would be shifted for around two hours and hot water production for up to 12 hours. While this modelling does not include a thermal store, a thermal store would increase the shifting period
    - We assume an average energy efficiency, equivalent to a drop in internal temperature of 3 degrees over five hours, with an indoor temperature of 20 degrees and outdoor temperature of 0 degrees. This equates to a loss of around 10% of thermal energy in two hours
- The savings potential will also depend on how well optimised the renewable technologies are in responding as a harmonious single system in each household. We do not believe that there are commercial services that currently allow the maximum benefits of flexibility across all assets. Our model does not assume the heat pump behaves differently with the addition of the battery.

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[3] Profile Classes are used to represent large populations of similar customers. Profile Class 1 represents *Domestic Unrestricted Customers* (i.e. a typical domestic customer on a standard meter)

[4] This is the industry standard values for the annual gas and electricity usage of a typical domestic consumer, and are used to derive the typical bills quoted in the publication of price cap and Energy Price Guarantee (EPG) updates. TDCVs can also be used by suppliers and price comparison websites in instances where individual consumers' data is unavailable

[5] Heat pump flexibility is an ongoing conversation with no single solution currently taking precedent over any others. Trials continue to be carried out to establish the best approach to both ensure household comfort while supporting the wider Net Zero targets and decrease demand on the grid

4 Results

This section presents the key findings of our analysis.

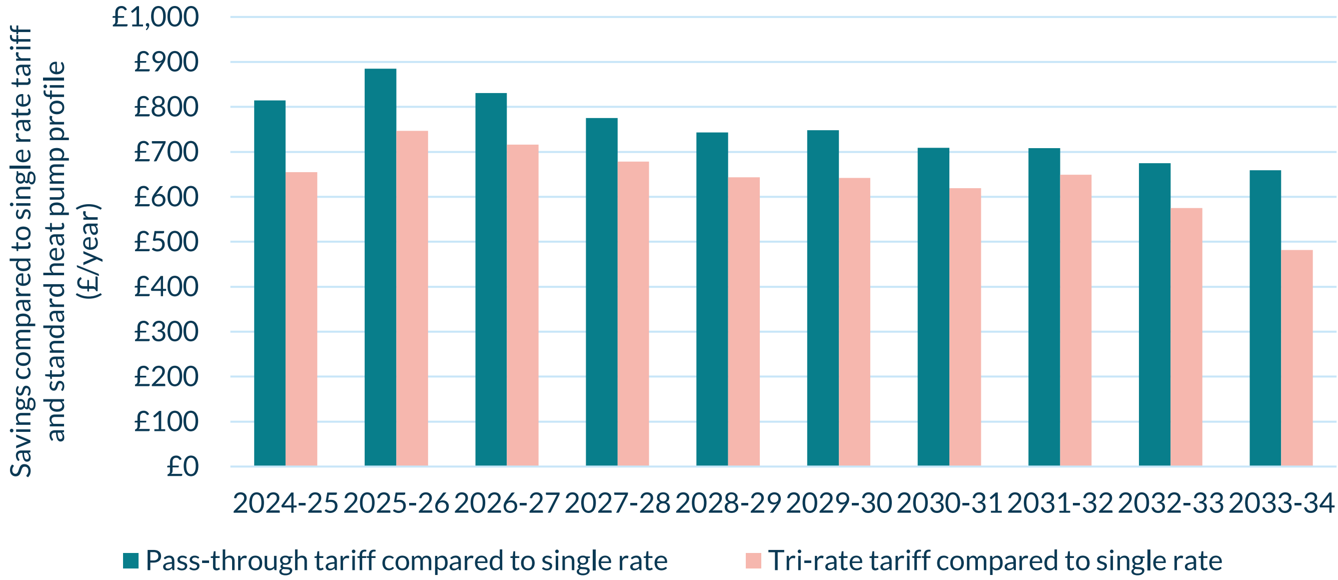
1. Consumers can make savings when the heat pump is used flexibly on a pass-through and tri-rate tariff compared to a standard heat pump profile on a single rate tariff

2. Adding solar and battery storage assets further increases the overall savings

Flexing a heat pump on a pass-through or tri-rate tariff presents savings compared to a standard profile on a single rate tariff

We found average annual savings of £640-£750/year by operating a heat pump flexibly on a time of use tariff (pass-through or tri-rate) compared to a single rate tariff where the heat pump is operated on a standard heat pump profile. Figure 5 outlines the savings each year under a pass-through tariff and a tri-rate tariff.

Figure 5: Difference in annual cost of electricity between time of use tariffs (flexible heat pump) compared to the single rate tariff (standard heat pump profile)



Source: Cornwall Insight

Under the modelled pass-through tariff, a heat pump used flexibly would save an average of £750/year compared to a consumer on a single rate tariff operating a standard heat pump profile (i.e. no flexibility), reflecting the higher prices of the single rate tariff under the hedging and risk approach used.

The heat pump responds to price signals in the pass-through tariff, and avoids consuming electricity during higher cost periods. These are intrinsically unpredictable to forecast (and expected to stay so in the short to medium term) and are based largely on the underlying wholesale electricity price. Typically, more flexibility is deployed in response to the pass-through price signal in the morning and evening when network charges are higher.

Therefore the main two sources of saving in the pass-through tariff with flexibility scenario are achieved via the purchase costs of wholesale electricity and lower network costs. Pre-heating when electricity costs are lower results in a lower overall cost in purchasing electricity. Network costs are also lower with flexibility as the customer is exposed to the time-based network charge elements under the tariff and these support the price signal that rewards pre-heating outside of peak network charging periods.

Under a tri-rate tariff, a heat pump used flexibly sees average savings of £640/year compared to a consumer on a single rate tariff operating a standard heat pump profile. Demand dips are easily forecastable under the tri-rate tariff, and may be more easily anticipated by a consumer. The highest cost period occurs for three hours during weekday evenings, so the heat pump avoids consumption during these periods, effectively resulting in no heating being undertaken during these periods.

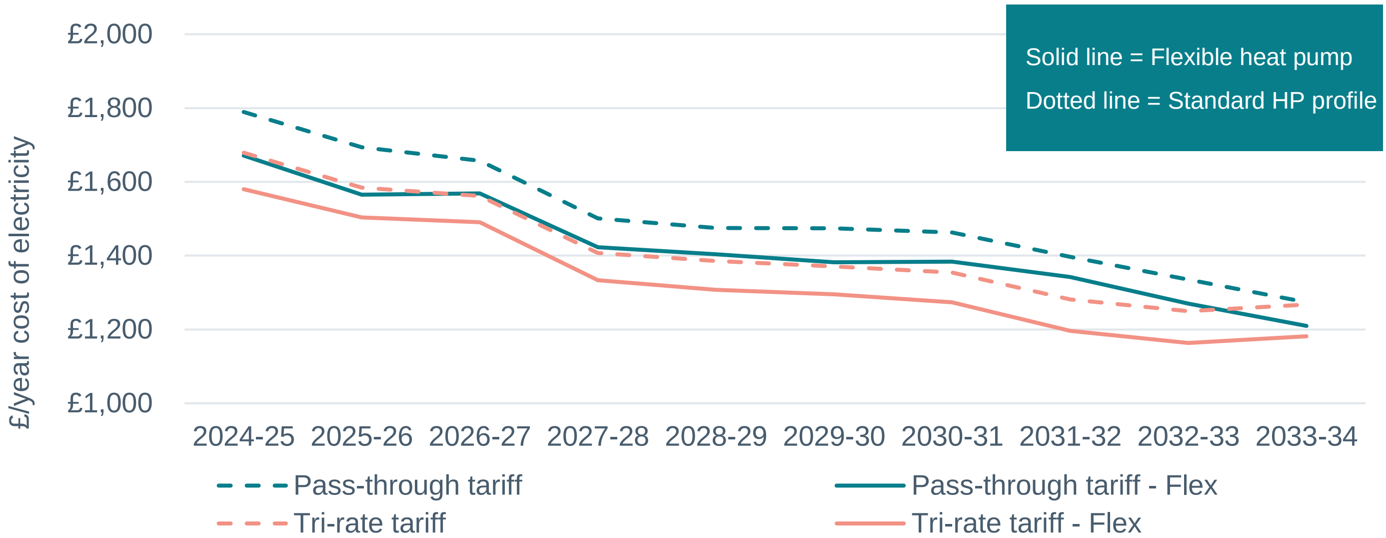
Our findings highlight the strength of demand signals and the importance of avoiding demand during these peak periods. On particularly cold days, it may be increase heat pump usage in buildings during this peak period in order to maintain customer comfort.

Using a heat pump flexibly on pass-through and tri-rate tariff structures unlock savings compared to not flexing

Our analysis demonstrates annual electricity price savings when operating a heat pump flexibly on a pass-through or tri-rate tariff, compared to a standard heat pump demand profile on the same tariff structures. The pass-through tariff saves £84/year using a heat pump flexibly, compared to £82/year on a tri-rate tariff. In each scenario, the flexible heat pump responds to price signals by avoiding consuming electricity during high priced periods, instead heating the home in advance during lower priced periods.

Figure 6 compares the average annual price of electricity achieved by flexing the heat pump under the pass-through and tri-rate tariffs (solid lines) to the same tariff structures when not flexing the heat pump in response to the price signals (dashed line).

Figure 6: Average annual cost of electricity (£/year) for with-flexibility scenarios against the "standard heat pump profile" comparators[6]



Source: Cornwall Insight

For comparison, flexing a heat pump whilst on a single-rate tariff results in a greater average annual cost of electricity. Flexing a heat pump on a single rate tariff results in an additional £46/year on average across the 10-year modelled period than without flexing due to higher electricity consumption of pre-heating a home to facilitate the turn-down flexibility actions but without any price incentives. *However, we note that we would not*

[6] The downward trend of tariff costs seen in Figure 3 relates to the increase of renewable energy coming online from sources delivered at relatively low marginal costs.

expect a user to undertake flexibility under this tariff structure in reality, unless other incentives were provided. Modelling of this scenario has been undertaken for comparison purposes only.

Higher savings can be accessed by adding solar PV and battery storage assets to the household

For pass-through and tri-rate tariffs, the addition of solar PV and battery storage technologies result in consumption peaking in the morning and evening, but with lower consumption from the grid during the middle of the day and early evening when solar is generating.

Our modelling found that savings increased when solar PV was added. Under the pass-through tariff, adding solar PV resulted in an average annual saving of £483/year, when used flexibly alongside the heat pump. The solar PV avoids electricity purchase costs, with solar PV generation consumed onsite in the first instance.

The addition of battery storage technology alongside the solar PV produces an even greater saving of £773/year on average. The battery charges using electricity from the installed solar PV or responds to prices in the wholesale market, taking the most efficient action to reduce costs to the household.

Figure 7 compares the average annual savings under a pass-through tariff with different assets and flexibility response, compared to a pass-through tariff with a standard heat pump profile.

Figure 7: Average annual savings under the pass-through tariff with and without assets

Tariffs	Flexibility	Savings per year compared to a pass-through tariff with a standard heat pump profile
Pass-through – Flexible heat pump	Heat pump responds to price signals	£84
Pass-through - Solar PV	Heat pump and solar PV respond to price signals	£483
Pass-through - Solar PV + battery storage	Heat pump, solar PV and battery storage respond to price signals	£773
Pass-through - Solar PV + battery storage (limited flex)	Solar PV and battery storage respond to price signals (the heat pump does not respond)	£1,002

Source: Cornwall Insight

Savings increased further when the heat pump was limited in its flexible response

Under the pass-through tariff structure, the modelled household saw lower annual costs when the heat pump was operated with no flexible control compared to when flexibility was present.

We consider this to represent two main factors:

- The additional electricity demand associated with operating the pre-heating schedule associated with the flexible heat pump. This requires additional power purchases and associated costs
- The treatment of co-optimisation of heat pump and battery storage activity within the optimisation model that we have used. Under the modelling approach used in this project, the flexible heat pump demand is derived separately and then used as a fixed input under scenarios battery storage and solar PV technologies are also present

As a result, the flexible heat pump schedule is not adjusted based on the presence of the battery asset. While this may limit the ability of the model to assess the value of co-optimising the heat pump pre-heating schedule alongside the battery storage technology, we believe this reflects the challenges consumers face when seeking to co-optimise multiple technologies without full integration.

Under a fully co-optimised system, we would expect to see greater savings achieved. Therefore the real world provision of interoperability across different technologies and services will be an important step to maximise the value of flexible assets in homes.

We see a similar trend under the tri-rate tariff scenarios with installed solar PV and battery storage technologies but no heat pump flexibility offering the greatest overall savings relative to the other tri-rate scenarios.

Carbon Emissions fall under these scenarios, but savings are relatively small

Our modelling results see additional energy imported into homes during the middle of the day in order to displace energy imports that are anticipated to occur later during the high-cost periods.

In GB, the highest cost period for energy correlates with the period where energy demand is at its highest. In order to meet this demand, a large amount of energy generation sources are turned on, including gas generation technologies. Therefore the periods where carbon emissions are at their highest also have a tendency to align with those high periods of cost and demand.

By acting to avoid peak costs, heat pumps with smart capabilities also avoid periods of carbon emissions. On an average basis, across winter months (October to March, inclusive), emissions are much higher in these periods, with a significant difference between evening peak emissions levels and midday emissions levels observed.

With an average annual carbon emissions volume shift of 1.4MWh for the pass-through tariff, and 0.7MWh for the tri-rate, and losses of around 10% of useful heat, this allows a smart heat pump which is flexibly responding to price signals, also to avoid emissions of 11.6-37.8kgCO_2e/year. A heat pump that is operated with a primary aim to avoid carbon emissions may achieve higher emission savings.

For context, the carbon savings associated with replacing a gas boiler with a heat pump are ~2,400kgCO2/year.

The savings for solar-equipped households are greater still, as these can make better use of the zero-carbon solar power generation, with better marginal reductions in emissions.

Figure 8 presents a comparison of carbon emissions savings across the range of tariffs.

Figure 8: Carbon emissions comparison

Year	Annual emissions from gas boiler (kgCO2e/year)	Annual emissions from non-flexible electricity consumption (kgCO2e/year)	Additional annual saving from flexibility under Pass-through tariff (kgCO2e/year)	Additional annual saving from flexibility Tri-rate tariff (kgCO2e/year)
2025-26	2,448	468	37.80	18.90
2027-28	2.448	408	29.48	14.74
2030-31	2,448	400	24.44	12.22
2033-34	2,448	36	23.18	11.59

Source: Cornwall Insight

5 Future Considerations

While manual changes to heat pumps in response to frequent price triggers may be unrealistic, progress has been made in developing smart heating control standards, through the smart mandate under the Smart Secure Electricity Systems Programme, and British Standards Institution.

By 2035, the majority of heat pumps are expected to be produced with smart control technology , supporting optimisation and financial savings for consumers. Electricity supplied to heat pumps would be accessed and controlled remotely by the heat pump manufacturer, the energy supplier, or a different flexibility provider, typically within a comfort range pre-agreed with the consumer to maintain comfort levels.

As higher numbers of heat pumps are installed, we would expect to see a variety of available tariffs beyond the ones modelled here that will help consumers take advantage of heat pump flexibility, as well as any other installed technologies with the ability to optimise their energy use. This could accommodate a greater range of consumer preferences regarding the frequency of change in tariff rates, the potential for bundled services and propositions, and development of Heat as a Service propositions.

Our modelling found that the addition of renewable energy assets further increases the potential operational savings for households with these installed. Home renewable technologies are increasingly offered to consumers in combined packages, with access to preferential export or import rates in some cases. Installation costs are expected to fall over time, with a range of purchasing structures continuing to develop (including 0% finance options) providing a range of options to households. As propositions in flexibility are developed, it will be important to ensure they are able to deliver interoperability across the technologies within a home to deliver maximum value to households.

With increasing levels of energy market change, including higher uptake of behind-the-meter technologies, new tariff structures, and access to potential new revenue streams, it will be important to communicate to consumers how changes in market conditions (including wholesale electricity prices) plays a role in their costs and rate of savings. Clear and transparent communication in presenting proposition options will be essential to achieving informed decision making, and ultimately delivering a smarter, more flexible energy market.

6 About Cornwall Insight

Getting to grips with the intricacies embedded in the energy market can be a daunting task. There is a wealth of information online to help you keep up to date with the latest developments, but finding what you are looking for and understanding the impact to your business can be tough. That's where Cornwall Insight can help, by providing independent and trusted expertise.

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7 About Nesta

Nesta is the UK's innovation agency for social good. They design, test and scale solutions to society's biggest problems. Nesta's three missions are to give every child a fair start, help people live healthy lives and create a sustainable future where the economy works for both people and the planet.

For over 20 years, Nesta has worked to support, encourage and inspire innovation. They work in three roles: as an innovation partner working with frontline organisations to design and test new solutions, as a venture builder supporting new and early-stage businesses and as a system shaper creating the conditions for innovation. Harnessing the rigour of science and the creativity of design, Nesta works relentlessly to change millions of lives for the better.

Find out more at nesta.org.uk

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