The economics of heat pumps and the (un)intended consequences of government policy

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Abstract:

In Europe, space and water heating account for approximately 80% of final energy use in the domestic sector. For many European countries the electrification of heat provision, via heat pumps (HPs), provides a promising decarbonisation pathway. The UK is no different, but recently concerns have been raised about the financial attractiveness of HPs given how, through various policy choices, taxes and levies are applied more heavily on electricity bills than gas bills. In this paper, we critically examine this argument by assessing the financial attractiveness of HPs across their lifetime for a typical UK household and within the current UK tax and regulatory regime. The results suggest taxes and levies do weaken the economic case for HPs: their current distribution having an unintended impact on the economics of HPs. Nonetheless, they are not the only reason for HPs comparative financial disadvantage. Upfront costs and HP performance, both influence the extent to which taxes and levies impact the economics of HPs. The results have implications for the future deployment of HPs in the UK and point towards policies to increase deployment (to drive down costs) and increase HP performance as being important.

Keywords:

- Heat pumps,
- Low carbon space heating
- Taxes and levies,
- Renewable Heat Incentive

Research highlights:

- Review of UK taxes and levies on energy suppliers 2001-2020
- Assessment of lifetime economic competitiveness of heat pumps
- Taxes and levies weaken the economic competitiveness of heat pumps
- Upfront cost and HP performance are critical
- Policies to increase HP deployment and performance are key for decarbonisation

1. Introduction

In Europe, space and water heating are thought to account for up to 80% of final domestic energy use (European Commission, 2016; Heinen et al., 2018). Across the EU, progress at decarbonizing space and water heating has been mixed, generally poor and largely reliant upon the increased use of biomass (European Commission, 2016). To decarbonize domestic heat a combination of improved building energy efficiency and onsite renewable generation is thought necessary as well as utilization of waste industrial heat and the expansion of district heating (CCC, 2016; Maclean et al., 2016; Garcia et al., 2012). Each Member State faces different starting conditions but common across decarbonisation pathways is a focus on electrifying heat provision (Sahni et al., 2017; IEA, 2018).

The UK is no exception and has for many years viewed heat decarbonization as a process of widespread electrification via heat pumps (HPs) coupled with district heating in heat dense areas (CCC, 2016; DECC, 2012, 2013). More recently, this pathway has been challenged, most notably by the idea of repurposing the gas grid to carry hydrogen, although again coupled with electrification for households off the gas grid (BEIS, 2018a; Dodds and Demoullin, 2013; Dodds and McDowall, 2013; Lowes et al., 2018; Maclean et al., 2016; Ofgem, 2016). Whilst a range of uncertainties exist, there is considerable agreement that a substantial level of electrification is required (BEIS, 2018a; Chaudry et al., 2015; Webb, 2016; ETI, 2015).

In this paper we tackle an important but so far overlooked issue for the electrification of domestic heat provision: the economic competitiveness of HPs in the context of the UK government's current tax and regulatory regime. Taxes and levies placed on the UK energy market have received considerable attention in the last decade for their social and distributional impacts (e.g. Barrett et al., 2018; CCC, 2017, 2011; Frerk and MacLean, 2017; Helm, 2017; Heptonstall and Gross, 2018; Preston, 2012). As far as we are aware, the impacts of the UK government's tax and regulatory regime on the economics of HPs and electrified heating more broadly, has received little academic attention to date.

In 2016, the UK Committee on Climate Change (CCC) argued the economic "unattractiveness of some [low carbon heating systems] in part reflects current balance of tax and regulatory costs on energy bills" because "the costs of funding low-carbon policies are significantly larger for electricity than gas or oil heating, and the full carbon costs are not reflected in the pricing of heating fuels" (CCC, 2016, 12). They conclude the existing UK tax and regulatory regime subsequently creates "perverse market incentives that work against low-carbon [electrified heating]" (CCC, 2016, 68). Two areas of EU and UK policy are responsible for this. The first area includes the EU Emissions Trading Scheme (EU ETS) and carbon floor price in the UK, that impose a carbon price on electricity but not on gas. These taxes are passed through to consumers within the wholesale market price of electricity. The second area comprises an increasing number of UK levies placed on energy suppliers to pay for a range of environmental and social objectives. The cost of these levies is again passed through to households. Together these taxes and levies increase the price of electricity more than the price of gas. This point has been recognised by others (Advani et al., 2013; Grubb and Drummond, 2018; Trinomics, 2018; Vijay and Hawkes, 2017) but to date, has received little attention in the context of technology attractiveness. This article helps to fill this gap.

The paper subsequently (a) examines the origins and growth of taxes and levies placed on the UK energy market and (b) assesses the impact of taxes and levies on the economic competitiveness of HPs now and into the future, as a combination of capital and installation costs, yearly fuel costs, and lifetime costs for a typical UK household. In doing so we assess the *unintended* consequences of UK government policy: the extent to which current government policies weaken the economic case for HPs. To understand the *intended* consequences of UK government policy we then (c) assess the extent to which the Renewable

Heat Incentive (RHI) – the UK government's primary policy to incentivize the uptake of renewable heating technologies – improves the economic attractiveness of domestic HPs.

The paper proceeds as follows. Section 2 reviews the taxes and levies placed on the UK energy market since 2001. Section 3 sets out our approach to assessing the economic competitiveness of HPs, the technologies compared, assumptions made, and analysis step taken. The results are presented and discussed, in sections 4 and 5 respectively. Section 6 concludes with policy recommendations.

2. Taxes and levies influencing the UK energy market

Taxes have always been applied to the sale of electricity and gas (i.e. VAT) but only recently have taxes been introduced for environmental reasons. Carbon pricing was introduced in 2005 via the European Union's Emissions Trading Scheme (EU ETS). The EU ETS places a cap on the carbon dioxide emitted by large European businesses and creates a market for carbon allowances. It is now in its third stage and covers 45% of EU emissions, including the generation of electricity. As a cost incurred by electricity generators, the EU ETS increases the wholesale price of electricity, which is passed on to all electricity customers. In the UK the Carbon price floor (UK CPF) was introduced on 1st April 2013 to support the price of carbon for UK-based businesses. The UK CPF further increases the price of electricity, which is again passed through to all electricity customers.

Alongside taxes, environmental and social levies are the other means through which government policies impact the gas and electricity bills. Environmental and social levies oblige energy companies above a certain size (more than 250,000 customers) to achieve a range of targets. The principle behind recovering the costs associated with environmental and social policies via consumer energy bills is not new (Rosenow, 2012). But since 2001 the cost of environmental and social policies on energy bills has risen steadily. From 2010, there have been multiple changes to domestic energy efficiency and renewables policy as well as the introduction of new policy areas. Figure 1 provides an overview of these levies, which are introduced further below.

In 2002 the first government support program explicitly designed to support renewable electricity generation was introduced. *The Renewables Obligation* (RO) required energy suppliers to source a definite proportion of their energy from renewable sources or pay a buy-out price (Woodman and Mitchell, 2011). The RO ran for 15 years and closed to new generating capacity in April 2017. In 2010 *the Feed-in Tariff scheme* (FiTs) was introduced to support a range of small-scale renewable electricity generating technologies under 5 MWs. Under FITs, energy suppliers are required to pay fixed rates to eligible renewable energy generators for electricity generated and exported to the national gird. All licensed suppliers are required to participate in some part of the scheme depending on their size and all suppliers are required to contribute to the costs of the scheme, redistributed to where claims are made, via the UK energy regulator, Ofgem. FiTs closed to new applicants in April 2019. Costs associated with the RO and FITs are passed through to energy users, and particularly domestic customers.

In 2013 the Energy Act was passed. It aimed to control the costs of environmental levies – particularly the rising costs associated with the RO and FITs - and deal with the increasing challenges posed by higher amounts of variable generation capacity coming on to the grid. It legislated for the closure of the RO and introduced two new mechanisms. *Contracts for Difference* (CfD) was designed as a new mechanism to support all forms of low carbon generation (renewables, nuclear and carbon capture and sequestration) by providing a stable price. The first contract auction was held in February 2015. The cost of CfD will be met by consumers through a levy on electricity supplies. *The Capacity Market* (CM) seeks to enhance the security of electricity supply by offering a steady, predictable revenue stream to all 'capacity providers' whether new and existing power stations, electricity storage or demand response. The costs of the CM will be levied on electricity bills from 2018/19[1].

Supplier obligations, which incentivise the deployment of domestic energy efficiency measures and aim to reduce fuel poverty have also experienced frequent changes to policy instruments, targets and associated costs (Rosenow, 2012). Between 2008 and 2012 *the Carbon Emissions Reduction Target* (CERT) and *the Community Energy Saving Programme* (CESP) were the government's two main policy programs to increase the energy efficiency of UK households. CERT obliged large energy suppliers to promote the uptake of energy efficiency measures in domestic properties. CESP obliged large energy suppliers to target the most deprived geographical areas in the UK with domestic energy efficiency improvements. Both CERT and CESP were closed at the end of 2012. In January 2013, *the Energy Company Obligation* (ECO) came into force and aimed to reduce carbon emissions and tackle fuel poverty by funding energy efficiency measures in difficult to treat housing and the homes of 'those most in need'. The scheme has subsequently been amended but is currently funded to 2022.

In April 2012, *the Warm Homes Discount* (WHD) was introduced and provides a one-off annual rebate on winter electricity bills for vulnerable or potentially vulnerable customers. Costs are passed through to customers. The scheme is currently set to run until 2020-21. The UK government has also set a target to install smart meters in all homes and 2 million small businesses by 2020. Delivery of smart meters is placed on energy suppliers with costs expected to be placed on consumer bills (Sovacool et al., 2017).

[1] In their assessment of policy costs for the determination of a 'tariff cap' on UK domestic gas and electricity tariffs Ofgem argues costs derived from the CM should be considered as wholesale energy costs. Here, we include CM costs for two reasons. First, costs associated with the CM derive as a consequence of a policy decision (to shift towards increasingly variable sources of generation). It is also a policy decision to pass on these costs to consumers via bills (c.f. general taxation). Second, in the following analysis, we utilise CCC cost estimates of current and future electricity and gas tariffs where CM costs are included under 'climate policy costs'. For consistency and comparability with the CCC approach, we allocated CM costs as a levy.

In each case the costs associated with meeting these levies are placed on energy suppliers and in turn, are assumed to be passed through to domestic energy bills (CCC, 2017; National Audit Office, 2016). Estimating the actual cost of these levies is not easy. All levies employ market mechanisms, designed to minimize costs through competition between suppliers: suppliers are encouraged to meet legislated targets at least cost and therefore be able to offer lower, more competitive electricity and gas tariffs to potential customers. Despite this, and since 2009, concern has grown over the extent of these levies. In 2010 this concern resulted in the introduction of the Levy Control Framework (Lockwood, 2016) and in 2017 a government-commissioned 'Cost of Energy review' (Helm, 2017).

Overall, what emerges is a complex policy landscape in which multiple government policies impact the price domestic consumers pay for gas and electricity. Whilst complex, there is a consensus that this policy mix has resulted in lower domestic energy bills overall (CCC, 2017; DECC 2014). Policies pose a cost through delivery but typically result in a reduction in household energy bills. Complex interactions and outcomes also explain much of the continuing controversy around energy bills and government policy (Heptonstall and Gross, 2018). Nonetheless, it remains that through various policy choices current taxes and levies are applied more heavily to electricity than gas bills. It is this cumulative impact of policy and whether it now has the unintended consequence of making HP financially unattractive that is explored below.

In doing so, we take account of the *Renewable Heat Incentive* (RHI). Neither a tax nor levy, the domestic RHI[2] was introduced in April 2014 and is the primary UK government policy to support the uptake of renewable heating technologies (Connor et al., 2015). It supports a range of technologies including HPs, biomass boilers, and solar thermal systems by providing quarterly financial payments for seven years.

[2] The non-domestic RHI was introduced in 2011 and like its domestic counterpart, is also funded via general taxation and so has no impact on domestic energy bills.

Unlike, the levies outlined above, the RHI is funded via general taxation and does not influence the price households pay for electricity or gas. The RHI is currently funded to March 2021.

3. Technologies, data and modelling approach

3.1 Basic approach

To assess the impact of UK taxes and levies on the financial attractiveness of UK domestic space and water low carbon heating systems over the long-term the following metrics become important:

a) The ability to supply sufficient heat to maintain comfort year-round.

b) The carbon intensity of the heating system (e.g. gCO_2/annum).

c) The cost-effectiveness of the heating system, in terms of upfront capital outlay, yearly fuel costs and lifetime cost (i.e. net present cost).

These three metrics are considered in this paper to examine the impact of policies on the economic attractiveness of low carbon technologies. The thermal efficiency of the housing stock presents a further underlying factor. This metric is incorporated within the following discussion by considering the current thermal efficiency of a typical UK household while determining its heating demand. Though increases in the energy efficiency of UK households are expected between now and 2050 as a result of a range of government programs (e.g. ECO) and is considered vital to make HP work efficiently (Bergman, 2012; CCC, 2016; Webb, 2016), in the following calculations we assume it remains constant. Equally important for electrification of heat provision but not discussed here, is the impact on the wider energy system (e.g. peak demand on the electricity system during the coldest days of the year, as addressed by Wilson et al., 2013), the social acceptability of different heating systems (in terms of noise, space requirements etc. (as addressed by Liu et al., 2014 for example), and consumer understanding of different heating systems.

These factors are no less important when considering the socio-technical potential of various low carbon heating systems but fall outside the scope of the present research.

3.2 Technologies under comparison

The technologies considered are:

a) **Gas Boilers** are used as the legacy technology and primary competitor to lower carbon heating systems within the study. The majority of UK households (85% or 23 million) are connected to the gas grid and use a gas boiler as their primary source of heating (CCC, 2016).

b) **Heat pumps (HP)** take low-temperature heat from the environment and convert it into high-temperature heat by the use of electrical energy. HPs can be used for space or water heating or a combination of the two. HPs are typically considered as a keystone technology through which the electrification of domestic heating can be achieved (BEIS, 2018; CCC, 2016). Three types of HP are considered in the analysis:

   a. **Air-source Heat Pumps (ASHPs),** as named, use air as the source of heat.

   b. **Ground-source Heat Pumps (GSHPs)** take heat from below ground and are thought to have a lower deployment potential in the UK than ASHPs due to the requirement of extensive ground works and therefore higher installation costs.

   c. **Hybrid HPs** combine a HP with a gas boiler, alongside a dedicated controller.

c) **Direct electric heaters** convert electricity into heat. Approximately 2 million households use electricity as the main source of heating in the UK, of which circa 0.5 million households are thought to use direct electric heaters (Ofgem, 2015). Direct electric heaters can take a variety of forms, including fan or convertor heaters, halogen and radiant heaters as well as oil-filled radiators.

d) **Storage heaters** are direct electric heaters designed to charge a thermal store (historically, during the night when there is less demand for electricity) and which can then release heat at times of need (historically, during the day when electricity demand is greater). Approximately 1.7 million UK households use storage heaters as their main source of heating (Ofgem, 2015). Quantum storage heaters – the most advanced storage heaters currently on the market – are employed in the study. Recently, attention has also turned to modern storage heaters as a complementary means to electrify domestic heating provision (alongside HPs) because of their potential to deliver useful heat whilst acting as a heat store and means to balance electricity generated from variable sources (Boait et al., 2017; Darby, 2018; Kerr et al., 2018).

3.3 Technology specific assumptions

Since April 2018 all new gas boilers installed in the UK have to meet a minimum efficiency of 92%[3]. To calculate the capital and installation cost of a new gas boiler we assume replacement boilers are located in the same position as before, thereby not incurring any increased cost.

Direct electric heaters and Quantum storage heaters are assumed to have an efficiency of 100% and to operate in conjunction with an electric immersion hot water heater (efficiency 100%). 5 radiators (4 large, 1 small) are assumed to be necessary to heat a typical UK household with 2 bedrooms. For storage heaters annual costs are calculated on the basis of an Economy 7 tariff, with 90% of electricity being consumed at lower night tariffs and 10% at higher, daytime tariffs.

Because HPs have an efficiency greater than 100%, the usefulness of a HP is captured within the coefficient of performance (COP). HP COPs vary between manufacturers and their products. But the primary factor determining Cops is the temperature of the source. Lower source temperatures make the HP work harder

[3]https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/718569/Boiler_Plus_Factsheet_v3.pdf

and result in a lower COP. There is no significant difference between standalone ASHP and Hybrid ASHP in terms of their COP (Foster et al., 2017). The COP provides an assessment of HPs under controlled conditions. In contrast, the seasonal performance factors (SPFs) provides an assessment of the overall efficiency of a HP in use, over a given operating period. It, therefore, seeks to take the variability in performance over temperatures ranges into account. SPFs subsequently report on field trials as opposed to manufacturer tests. Results from UK field trials indicate that SPF values vary significantly: for standalone ASHPs results range from 1.5 to 3.9 with a mean value of 2.44 whilst for hybrid ASHPs results range from 2.5 to 4 with a mean value of 3.1 (Fosters et al., 2017). The difference between standalone and HHP results from the boiler being used to 'top up' or provide all heat when source temperatures drop below a certain temperature. This means that the HP within a Hybrid system is only working at warmer temperatures when the HP is more efficient. These field trials occurred between 2011 and 2015. In the following analysis we use the mean, deemed SPF rating of ASHP and GSHPs from the RHI deployment database[4] and field trial results for Hybrid HPs (as reported in Foster et al. 2017).

When assessing the performance of hybrid HPs further considerations are warranted. These include whether the HP is used to supply hot water, what heat emitters (radiators) are used (low or high temperature) and how the combination of systems are used (principally a choice between working in parallel or switching between systems). Because of our focus on decarbonisation we assume the control strategy for the Hybrid HP is calibrated to minimise CO_2 emissions. In practice, this means that the HP is set to cover as much of the heating demand as possible, with the boiler used to top-up output temperatures where necessary or where the HP falls below a set efficiency. Field tests suggest a CO_2 minimisation strategy would result in HPs providing 80% of heating demand (Foster et al, 2017).

Table 1 provides a summary of heating system sizing and efficiencies used in the study.

[4] RHI deployment data: September 2018 (BEISb, 2018)

Heating system component costs derive from a report by Foster et al. (2017) on the potential role of Hybrid HPs in the UK's long-term decarbonisation of domestic heat, commissioned by the UK Department for Business, Energy and Industrial Strategy (BEIS). The report draws on a wide range of sources (existing literature, field trials and consultation with industry stakeholders) to present the most up-to-date examination of heating system components costs in the UK that we are aware of. In this report Foster et al. (2017) examine the potential of Hybrid HPs (c.f. ASHPS and GSHPs) in terms of carbon emission intensity, cost effectiveness and their impact on the wider energy system. In the current paper we take the same cost component assumptions and extend their analysis to examine the impact of government taxes and levies on the economics of domestic, low carbon heat provision. Our analysis of the carbon intensity of heating systems also extends the work of Foster et al. (2017) by comparing against a wider range of heating systems.

3.4 Household heat demand profiles

To assess the economic competitiveness of a range of domestic space and water heating systems we start with a typical demand profile. While considering the thermal demand of a household, care is taken to ensure that the data used is pertaining to the heating requirement of the house excluding the type of technology used for providing that service. Average space and water heating demand of a typical semi-detached household in the UK is considered as 11,050 and 1,950 kWh/annum (CCC, 2017). The heating demand of a typical household calculated using the Building Research Establishment's domestic energy model also results in a similar value. These values are used as a base value to compare the different technologies.

We assume that the typical household already has either a central heating system based on a gas boiler or a set of storage heaters installed. We also assume that the typical semi-detached house has 'normal' levels of insulation, thereby requiring a higher heat load to deliver comfortable temperature compared to new build, highly insulated households.

3.5 Electricity and gas price assumptions

Assumptions about electricity and gas prices are taken from the Committee on Climate Change's (CCC) commissioned work on UK Energy Prices and Bills (CCC, 2017). In this work, the Committee breaks down current and future electricity and gas bills into three component parts: (a) basic price components, including wholesale energy costs, supplier costs and transmission and distribution costs, (b) non-climate policy costs including social policies aimed at addressing fuel poverty, the smart meter delivery programme and VAT, and (c) climate policy costs including support for low carbon generation (CfD, RO etc), the EU ETS and UK CfP, supplier obligations and other policies to upgrade the transmission and distribution system to accommodate renewable generation. The basic price components from the report is used as a basis to arrive at prices for the years in between using linear projection. Figure 2 provides an overview of residential gas and electricity price components and annex B provides a breakdown of the components for each category.

3.6 Analysis Steps

The capacity of heating technologies under study are chosen to ensure they can deliver sufficient heat to maintain comfort year-round in a typical UK household. In the following analysis we compare (a) the carbon intensities of the different technologies to meet the same heat demand over a year, (b) capital and installation costs, (c) yearly fuel costs, (d) system net present costs (NPC), and (e) system net present costs with RHI payments. These steps are explained below.

a) Carbon intensity per unit of thermal demand:

The carbon emissions per unit of thermal demand associated with the use of each heating system is calculated using the following equation, where η is the efficiency of the conversion technology and SPF is the seasonal performance factor. This is multiplied by the heat demand of the household to arrive at the net emissions from different heating systems.

$$Carbon\ intensity = \begin{cases} \eta * carbon\ intensity\ of\ gas, for\ gas\ boiler \\ \frac{carbon\ intensity\ of\ electricity}{SPF}, for\ heat\ pumps \end{cases} \quad (1)$$

b) Capital and installation costs

Capital and installation costs are derived by summing costs associated with the heat conversion technology (e.g. the gas boiler, HP) as well as heat emitters (i.e. radiators), any controls and hot water tank cylinders., a breakdown of which is provided in Annex A.

c) Yearly fuel costs

Average yearly fuel cost is calculated using the following equation, where η is the year under consideration.

$$Fuel\ cost_n = Heat\ demand \times (Basic\ fuel\ cost_n + non - climate\ policy\ cost_n + climate\ policy\ cost_n) \quad (2)$$

d) Net present cost (NPC)

Net present cost (NPC) is calculated assuming a 15-year lifetime using the following equation, where the discount rate is 3.5% (Treasury, 2018, 7). In practice few, if any, households perform this sort of analysis.

$$NPC = Capital\ cost + installation\ cost + \sum_{n=0}^{14} \frac{maintenance\ cost_n + Fuel\ cost_n}{(1+discount\ rate)^n} \quad (3)$$

e) Net present cost with RHI

In the final analysis step, we incorporate technology specific payments from the Renewable Heat Incentive to assess in full the economic competitiveness of HPs under the current UK tax and regulatory regime. The RHI supports the uptake of lower carbon heating systems by providing quarterly financial payments for seven years. Payments are calculated on the basis of the properties heat demand (determined by its Energy Performance Certificate) adjusted by the deemed SPF of the HP installed, multiplied by the technology specific tariff rate. This results in annual payments, which are divided by four to reach quarterly payments as given in equation 4.

$$quarterly\ payment = \frac{Heat\ demand \times \left(1 - \frac{1}{SPF}\right) \times \left(\frac{tariff\ rate}{100}\right)}{4} \qquad (4)$$

Following a consultation in 2016 (BEIS, 2016), a number of changes were introduced to the RHI in order to focus the scheme on long-term decarbonisation and offer better value for money. In September 2017 ‘heat demand limits’ were introduced, to counter the increased value of installing HPs in larger householders. These limits come into force where a property’s heat demand breaches the heat demand limit. Since a typical semi-detached UK household uses less than the heat demand limit, the payments are calculated on the property’s heat demand. To further incentivise the uptake of ASHP and GSHPs their respective tariffs were increased. Finally, in an attempt to improve householder knowledge of HP efficiency and drive overall system improvements, two types of metering were introduced. ‘Metering for performance’ requires all HPs to install electricity meters to measure electrical input to all HP elements (compressor, circulation pump and/or compressor) and any subsidiary space and water heating devices (e.g. immersion heaters) unless they are standalone room heaters. ‘Metering for payment’ requires heat output to be measured where there is a backup fossil fuel heating installed (i.e. in Hybrid systems). Both forms of metering increase upfront costs. In the following calculations, the additional costs of metering are not included because there exist multiple means to achieve metering which depend on the system installed and location. At best, these costs are minimal (achieved through onboard electricity metering within the HP) and in the worst case require significant additional upfront capital (for standalone electricity, gas or heat metering or a combination thereof). Overall, new metering requirements will add to the upfront costs of installing HPs and would negatively impact HHP more than standalone HPs. Net present cost including RHI is calculated using the following equation,

$$NPC_{RHI} = Capital\ cost + installation\ cost + \sum_{n=0}^{14} \frac{(maintenance\ cost_n + Fuel\ cost_n - RHI\ payment_n)}{(1+discount\ rate)^n} \quad (5)$$

4. Results

4.1 Carbon intensity of heating systems

Carbon intensity of different heating technologies is calculated using equation (1) for the respective year under consideration. The results are shown in Figure 3. All HPs are less carbon intensive than the gas boiler. The differences between HPs is due to differences in SPFs achieved. Hybrid HPs have higher carbon intensity than standalone HPs because 20% of heat is assumed to be derived from the gas boiler. Expected reductions in the carbon intensity of electricity means the difference between hybrid and standalone HPs increases over time. Direct electric heaters and storage heaters share the same curve. Both are expected to become less carbon-intensive than gas boilers from circa 2022.

4.2 Capital and installation costs of heating systems

A breakdown of capital and installation costs of heating systems are shown in Figure 4. The results indicate the upfront cost of domestic heating systems varies widely. For a typical UK household – with space and water heating already delivered by a gas boiler – gas boilers have the cheapest capital and installation cost. All other heating systems carry an upfront cost premium under this model: HPs cost approximately £7-11,000 more given current costs, whilst electric heaters and storage heaters costs approximately £1,000 to £2,500 more respectively.

In reaching these results we note how some base assumptions can have a large impact on the capital and installation costs of heating systems. Whilst costs associated with gas boilers, electric and storage heaters are well known, variations in emitters used alongside control and heating strategy can have a large impact on HP capital and installation costs. For instance, it is possible for hybrid HPs to utilise existing high temperature emitters (thus saving £1800, but with the consequent need for higher temperatures, increasing the use of the gas boiler and subsequently increasing emissions). There is also some debate over whether a smaller HPs can be fitted in a hybrid scenario. Foster et al. (2017) suggest this is a possible means to reduce Hybrid HP costs. Our engagement with experts suggests whilst this is possible, a control strategy that seeks to minimise environmental impact and thereby only uses the boiler to provide heat when HP efficiencies drop below a certain point, requires an equivalent size HP to the standalone case. What we can say is the capital and installation costs of standalone and hybrid HPs are considerably more expensive than gas boilers. Electric oil-filled radiators and storage heaters are also more expensive at current prices and result in higher carbon emission up until 2022.

4.3 Average yearly fuel costs by heating system

Alongside capital and installation costs, yearly fuel costs are the primary means through which households pay for space and water heating. It is within gas and/or electricity costs that taxes and levies influence the economics of lower carbon heating systems. Figure 5 shows the yearly fuel costs for each heating system in

2016, 2020 and 2030. The red bars indicate the variation of the costs for worst- and best-case efficiencies/SPFs, all other factors remaining the same.

Across each of the three years analysed direct electric heaters are the most expensive, followed by storage heaters. This result isn't surprising. It is well known how households who rely on electric heating as their primary heat source face higher fuel bills than the average UK household (Ofgem, 2015). HPs have a comparable total annual fuel cost to the gas boiler, the best case being approximately £174 cheaper (ASHP and GSHPs in 2016) the worst case being approximately £255 more expensive (ASHP and GSHP in 2030) including sensitivity ranges. The difference between HPs in any given year is attributed to the SPFs. Over time all total annual fuel costs rise. However, the annual fuel costs for electrified heating increase more than gas boilers, thereby making electrified heating less competitive over time. This result derives from anticipated changes in the basic price components of electricity and gas and increases in taxes and levies over time, which are expected to fall more heavily on electricity bills than gas bills (figure 2). In practice this means HPs will be made increasingly less economically competitive against gas boilers over the coming decade.

These results also indicate the critical role SPFs have on the economic competitiveness of HPs. Where higher SPFs can be achieved, all HPs have an economic advantage over gas boilers under current government policies, potentially being nearly a quarter cheaper than gas boiler annual fuel costs. Where lower SPFs are achieved, all HPs have higher annual fuel costs than gas boilers. Crucially, this sensitivity to the SPF achieved gets greater overtime, implying the current distribution of taxes and levies will have an increased impact in the future. This result is in line with analysis performed by the CCC (2016). Overall, this suggests that government taxes and levies do influence the cost of operating HPs but that HPs have cheaper yearly running costs compared to gas boilers if a higher SPF can be achieved.

4.4 Net present cost of heating systems

Figure 6 shows the net present costs of the heating systems studied. It shows gas boilers have the lowest net present cost of all heating systems considered. The most expensive are direct electric heaters. Of note, storage heaters have comparable costs to GSHPs. Figure 7 also shows how taxes and levies make the economics of deploying electricity-based heating systems worse than they otherwise would be compared to gas boilers. In other words, taxes and levies work against moves towards low carbon, electrified heating. However, figure 7 further shows how the primary difference in cost for HPs stems not from taxes and levies but from capital and installation costs.

Here, the sensitivity of HP results to SPF achieved is much smaller. Higher SPFs still achieve reductions in lifetime costs (up to £2,500 cheaper) and lower SPFs result in higher lifetime costs (up to £2,750 more expensive) but the impact of SPFs to overall results is smaller because the majority of HP costs are associated with fixed capital and installation costs.

4.5 Economic impact of Renewable Heat Incentive on HP competitiveness

In the final part of the analysis, we analyse the intended outcomes of government policy and incorporate the impact of the RHI on the economic competitiveness of HPs. Figure shows the lifetime cost (NPC) of HPs both with and without RHI payments, compared to the lifetime cost of a gas boiler.

The results indicate the RHI has a significant impact, substantially reducing the lifetime cost of installing HPs compared to a gas boiler. GSHP become approximately £1000 cheaper over their lifetime than the gas boiler. ASHP and Hybrid HPs become approximately £1,500 more expensive than the gas boiler.

The results are also sensitive to SPFs achieved. Higher SPFs can reduce lifetime costs (as per figure 6). Higher SPFs also result in higher RHI payments, thereby further reducing HP lifetime costs when the RHI is factored in. Lower SPFs have the opposite effect, increasing lifetime costs and reducing RHI payments. Lower SPFs subsequently weaken the economic case for HPs. Under best case scenario of 4.1 SPF, lifetime cost of GSHP is less than that of boiler by around £3,500.

5. Discussion

These results suggest current government policies are causing unintended consequences to the economic competitiveness of HPs: Current government policies designed to variously support the uptake of low carbon electricity generation, increase the efficiency of the UK housing stock and reduce fuel poverty whilst largely successful on their own terms, negatively impact the economic competitiveness of domestic HPs. This is particularly the case when looking at annual fuel costs, which is where the impact of taxes and levies arises. Our results indicate taxes and levies will further reduce HP economic competitiveness over the coming decade. This result is underlined when looking solely at basic electricity and/or gas price components: Without levies (taxes are incorporated in the basic price components), it is clear HPs would be more financially attractive in any year under study than gas boilers. For storage heaters and direct electric heaters, the impact of taxes and levies is large and, generally, already appreciated by academics and policymakers.

These results provide support to the CCC (2016, 12) when it argued the economic “unattractiveness of some [domestic, low carbon, electrified heating systems] in part reflects current balance of tax and regulatory costs on energy bills”. Furthermore, the results explain how and why the balance of tax and regulatory costs *only partly* influence the economics of HPs.

By placing annual fuel costs (where taxes and levies arise) within a lifetime costs estimate of heating systems we can present a complete picture of the economic attractiveness of HPs under current UK policy. Doing so highlights an important, and widely recognised, point: HPs have higher upfront costs than gas boilers. Meanwhile, taxes and levies impact annual fuel bills. These taxes and levies subsequently effect lifetime costs (NPC) and make all HPs less financially competitive to a gas boiler over their lifetimes. Nonetheless, the impact of taxes and levies is relatively small when placed within the NPC analysis. Taxes and levies simply make uncompetitive technologies worse off. They do not substantially alter the competitiveness of HPs against gas boilers. The primary reason for this is the former's large upfront costs. This is an important qualifier to the CCC's argument. Because taxes and levies only impact fuel bills, there effect on competitiveness is therefore greater where annual fuel costs represent larger proportions of a heating systems lifetime costs, as in the case of a gas boiler (figure 8). However, for HPs annual fuel costs might represent as little as two fifths of a HPs lifetime cost and so taxes and levies placed on fuel bills have a far lower impact.

It is also important to consider the intended consequences of government policy in this area, namely the impact of the RHI on the economics of HPs. Our results indicate the RHI has a significant positive impact on the economics of HPs against gas boilers.

Finally, our analysis also indicates how the economic competitiveness of HPs is largely dependent on the SPF achieved. Higher SPFs make HPs more competitive compared to gas boilers in annual fuel costs, whilst lower SPF will cost more to run per year than a gas boiler. The sensitivity of lifetime costs to variations in SPF is much smaller, for the reason just stated. Nonetheless, SPFs become critical to HP competitiveness within the context of the RHI. Through the RHI the impact of SPFs is doubled. Higher SPFs result in a more efficient heating system, costing less to run. Higher SPFs also result in higher quarterly RHI payments, thereby providing a double benefit.

Overall, we conclude the current balance of UK tax and regulatory costs passed through to domestic electricity and gas bills does significantly weaken the economic case for switching from gas to lower carbon, electrified heating and specifically HPs. Nonetheless, the impact of taxes and levies, is less than suggested at first look because of the smaller proportion of lifetime costs that annual fuel bills make up. Meanwhile the RHI currently goes a long way in making HP economically attractive. Yet, crucially, this relies on achieving high SPFs.

7. Conclusion and policy implications

In the UK there is growing concern about the financial attractiveness of HPs against incumbent gas boilers, given how, through various policy choices, taxes and levies are applied more heavily on domestic electricity bills than gas. These policy choices have been taken for a variety of reasons. It is also widely agreed that these policy choices have been effective, at encouraging the increased deployment of lower carbon electricity generation and the upgrading of the UK's housing stock for instance. Nonetheless, there is now growing concern that they may be working against lower carbon domestic heating. In this paper, we analysed the financial attractiveness of HPs now and into the future as a combination of capital and installation costs, yearly fuel costs, and lifetime costs for a typical UK household in the context of the UK's current tax and regulatory regime. In doing so we have assessed the unintended consequences of UK government energy policy on the economics of HPs.

Our results show the current balance of taxes and levies negatively impact the economic competitiveness of HPs. This impact is most clearly seen within annual fuel costs. The impact of taxes and levies is still present but significantly reduced when viewed as a proportion of system lifetime costs. Our analysis highlights the high upfront costs associated with heat pumps and the critical role SPFs play in making HPs more financially attractive. Where higher SPF can be attained, the more economically attractive they are against gas boilers. Moreover, under the RHI the impact of higher SPFs is effectively doubled: higher SPFs result in lower annual fuel bills *and* a higher subsidy.

These results lead us to two policy recommendations:

1. Reduce HP capital and installation costs through increased deployment. Increasing deployment has the potential to reduce component costs (through economies of scale), increase competition (between installers, driving down prices), and reduce labour costs (through experience). To achieve this goal a variety of policy tools exist. Increased public procurement could encourage further market development. Demand could be fostered through national campaigns or awareness raising. Whilst, labour costs could be reduced if the government worked with industry to simplify installation procedures and accreditation. These options present a range of soft tools to increase deployment. Alternatively, capital grants or loans could be used and have been the subject of debate since the introduction of the RHI (Connor, 2013; Connor et al., 2015; Lowes et al., 2019).
2. Improve the SPF of installed HPs to reduce running costs and the impact of current taxes and levies. A variety of policy tools exist that could help to improve SPFs. The introduction of 'metering for performance' under the RHI is a step in the right direction but has two clear weaknesses. It relies on sufficient householder knowledge, to understand and interpret the data and it is unlikely to put pressure on installers (to perform better installations) as the effects of metering only become apparent during operation. Alternatively, policymakers could regularly revise the minimum required SPF to be eligible for the RHI (at present HPs have to meet a deemed SPF of 2.5 to be eligible). In the absence of the RHI, minimum performance standards, akin to boiler standards, could be used to drive up performance and remove the worst performing HP units from the market. The creation of an independent, national arbitration body presents a further option, which could guard against faulty or poor installations, including lower than expected SPFs. Finally,

government could work with installers and trade associations to improve all stages of HP installation, from initial feasibility and sizing, through installation and sign-off. This might include developing or improving MCS accreditation training.

These policy recommendations are of particular relevance to the UK government as it explores options to support the deployment of HPs following the planned closure of the RHI in March 2021. Our analysis and results are also relevant to other European countries in which a high proportion of households rely on gas for heating and where taxes and levies impact the price of electricity more than gas, such as Germany, France, Italy, and the Netherlands.

Acknowledgements

The authors gratefully acknowledge funding from the Oxford Martin School through the Oxford Martin Programme on Integrating Renewable Energy. The Oxford Martin School is a world-leading centre of pioneering research that addresses global challenges. Visit: www.oxfordmartin.ox.ac.uk for more information. The authors would also like to thank Sam Wassam, Jenny Hill, Tommy Moddy and Isabel Pether for their constructive comments on earlier drafts as well as the two anonymous reviewers.

Appendix A: Heating system component costs (Foster et al., 2017)

Item	Unit	Central cost estimate
Production costs		
Gas boiler, 24 kWth	£/unit	800
Heat pump, 5-11 kWth	£/kwth	625

Heat pump controller cost	£/unit	300
Hot water tank	£/litre	3
Quantum storage heater	£/unit	616
Electric oil filled radiators	£/unit	400
<u>Installation costs</u>		
HHP	£/building	2,500
ASHP	£/building	2,500
GSHP	£/building	6,700
Gas boiler	£/building	770
hot water storage	£/building	250
Replacement of low-temperature emitters	£/building	1,800
<u>Maintenance costs</u>		
HHP	£/unit/year	175
Heat pump	£/unit/year	175
Gas boiler	£/unit/year	175

Appendix B: Expected changes in residential electricity and gas price components 2016, 2020, 2030 (CCC, 2017)

Price component		2016	2020	2030
Electricity				
1	Wholesale exc. carbon price	5.4	5.5	7.5
	Supplier Costs + Margin	2.4	2.5	2.5
	Transmission	0.8	1.1	1.1
	Distribution	3.0	3.0	3.0
	Balancing	0.1	0.2	0.2
2	Carbon Price	0.8	0.8	1.2
	Support for Low Carbon	1.8	3.1	4.3
	Energy efficiency (low carbon)	0.2	0.0	0.2
	Capacity Market	0.0	0.4	0.9
	System integration costs - transmission	0.0	0.1	0.1
	System integration costs - intermittency	0.2	0.2	0.5
	Additional distribution costs	0.0	0.0	0.1
	Merit Order Effect	-0.6	-1.0	-1.5
3	Warm Homes Discount	0.2	0.2	0.2
	Energy efficiency (other)	0.2	0.3	0.2
	Smart Meters	0.2	0.3	0.0
	VAT	0.7	0.8	1.0
Total		15.4	17.4	21.4
Gas				

1	Wholesale Energy + Gas Storage	2.1	2.2	3.3
	Supplier Costs + Margin	1.0	1.2	1.2
	T&D	1.0	1.1	0.8
2	Energy efficiency (low-carbon)	0.0	0.0	0.1
	Impact of lower gas throughput	0.0	0.0	0.1
3	Warm Homes Discount	0.0	0.0	0.0
	Energy efficiency (other)	0.0	0.1	0.1
	Smart Meters	0.1	0.1	0.0
	VAT	0.2	0.2	0.3
Total		4.6	5.0	5.9

1 = Basic costs

2 = Climate policy costs

3 = Non-climate policy costs

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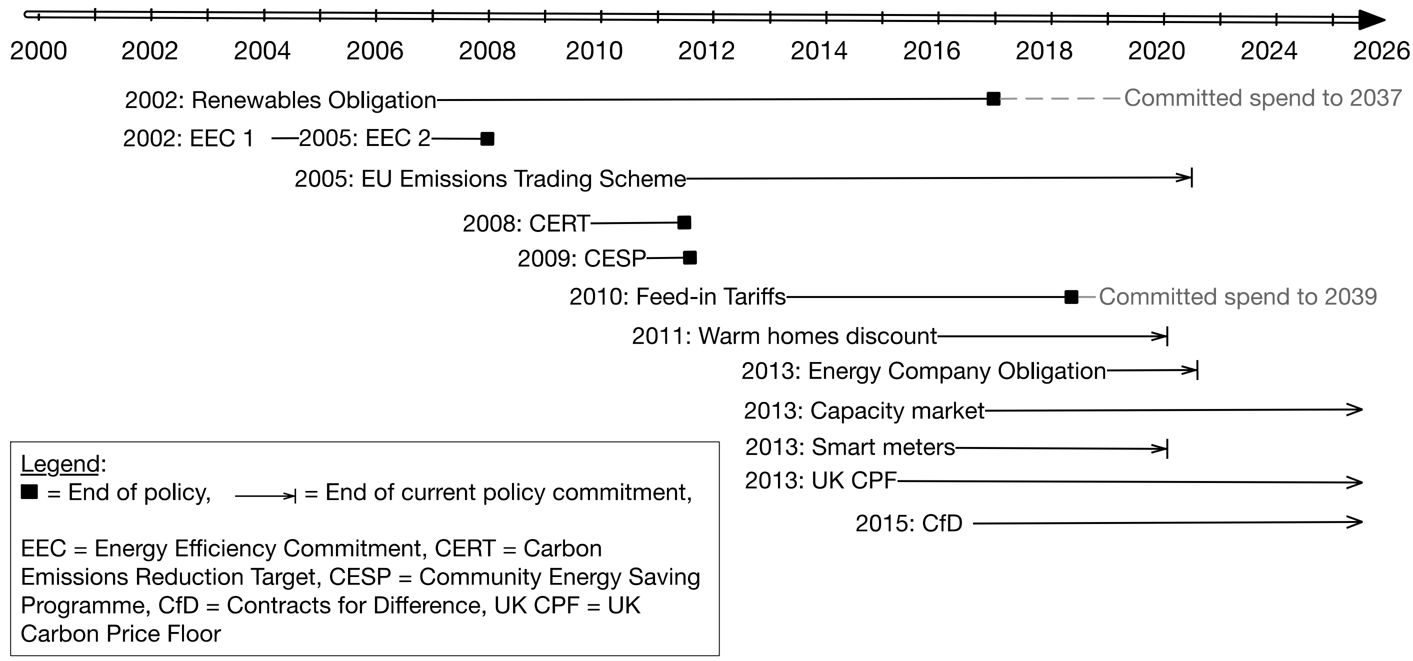

Figure 1: Taxes and levies influencing the UK energy market (Authors' own figure)

Table 1: Summary of heating system sizing and efficiencies

	Efficiency (mean)	SPF (mean)	Range	Reference
Gas boiler (24 kWth)	0.92		0.9-0.94	Boiler Plus (BEIS, 2018)
ASHP (6 kWth)		3	2.5-4.1	RHI deployment data: September 2018
GSHP (6 kWth)		3.3	2.5-4.1	RHI deployment data: September 2018
Hybrid (6 + 24 kWth)	0.92	3.1	2.5-4	Foster, Lyons & Walker (2017)
Storage heater (5 units)	1			BREDEM 2012: Technical description of the BRE Domestic Energy model (p.34)
Direct electric heater (5 units)	1			BREDEM 2012: Technical description of the BRE Domestic Energy model (p.34)

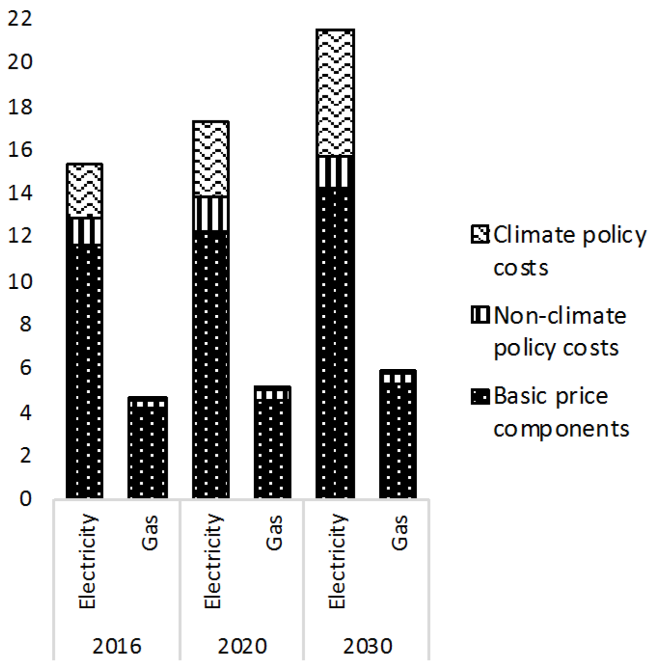

Figure 2: Residential gas and electricity price components 2016, 2020 and 2030 (p/kWh) (based on CCC, 2017)

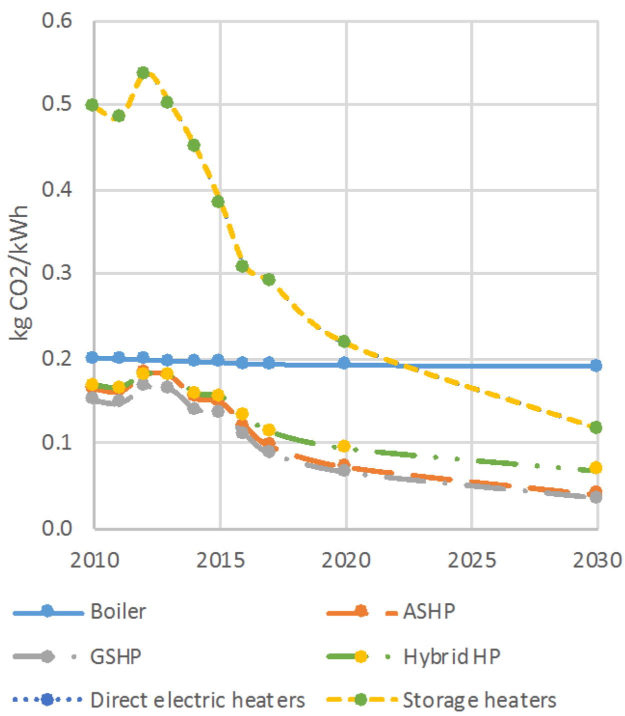

Figure 3: Carbon intensity of heating systems (kgCO_2/kWh)

(2010-2017 data taken from BEIS, 2018b; electricity projections for the years 2020 and 2030 taken from Foster et al. 2017; gas projections for 2020 and 2030 include an assumption of moving to the incorporation of 5% biomethane by 2050)

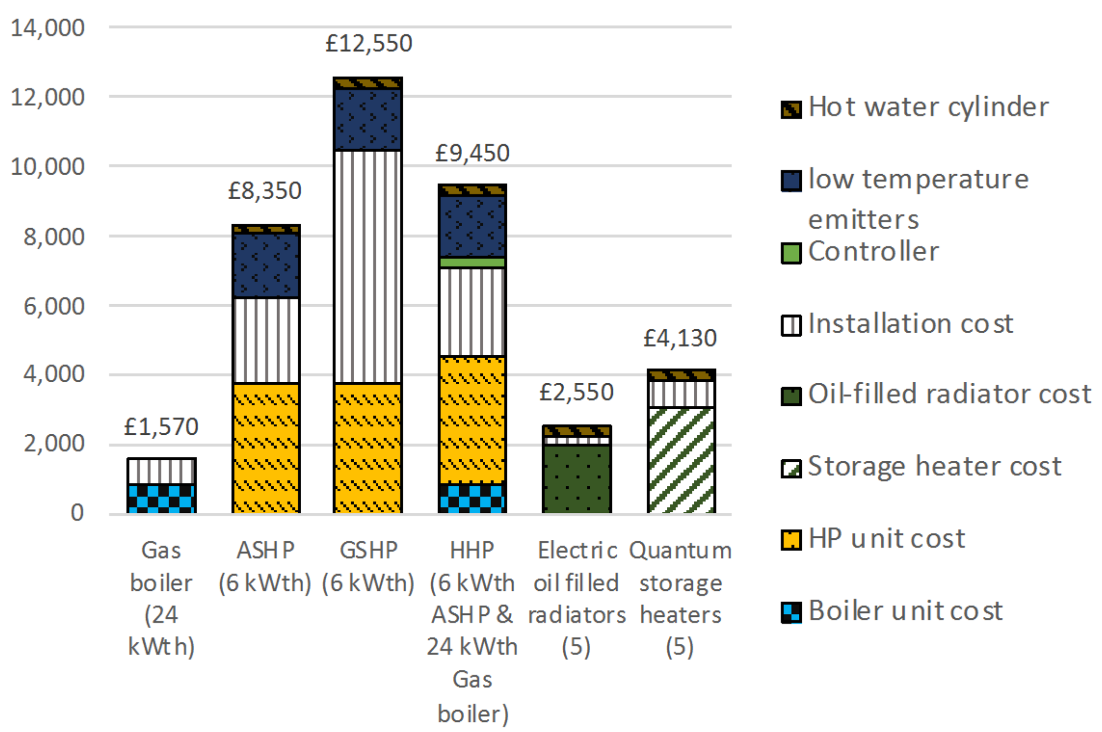

Figure 4: Upfront costs of heating systems for a typical semi-detached UK household (central cost estimate)

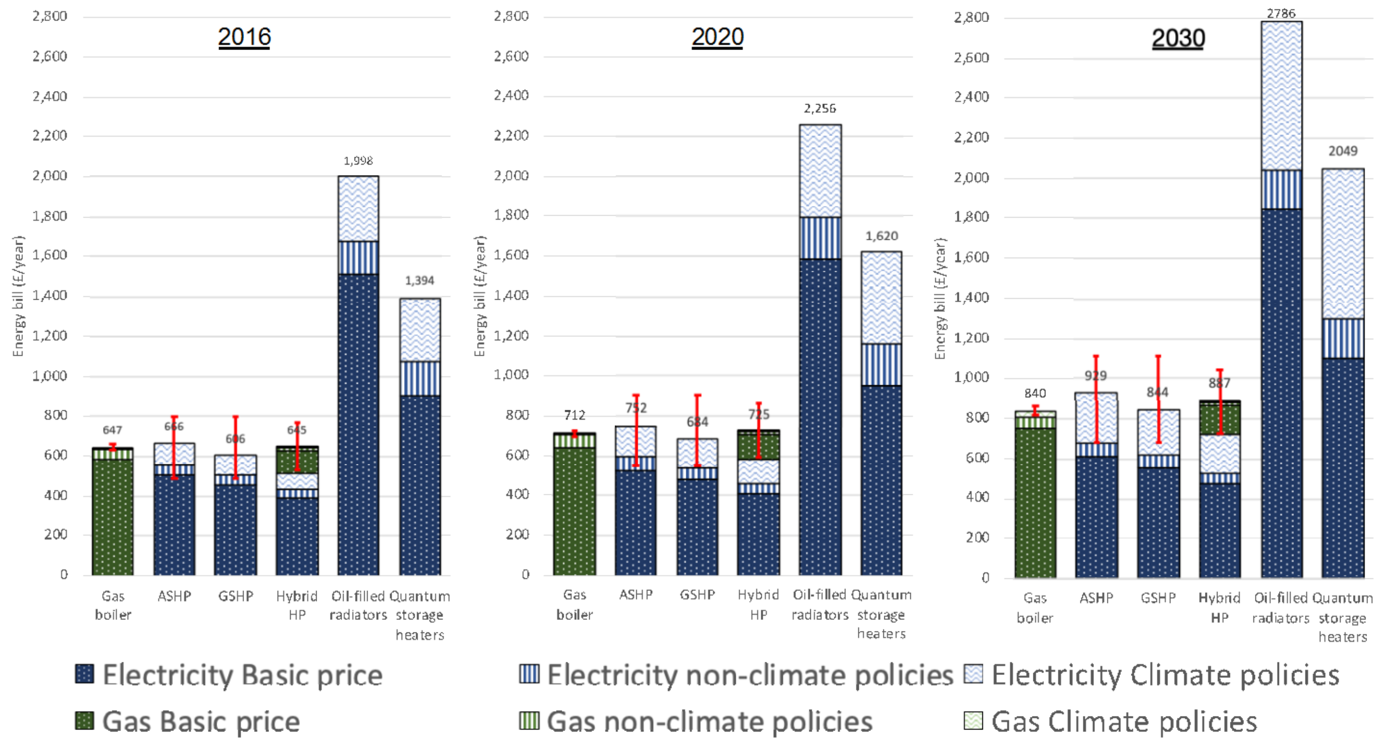

Figure 5: Yearly fuel costs for a typical UK semi-detached household in 2016, 2020, 2030

(the red bars show the variation of cost with efficiency/SPF, range of which is given in table 1, all other parameters remaining the same)

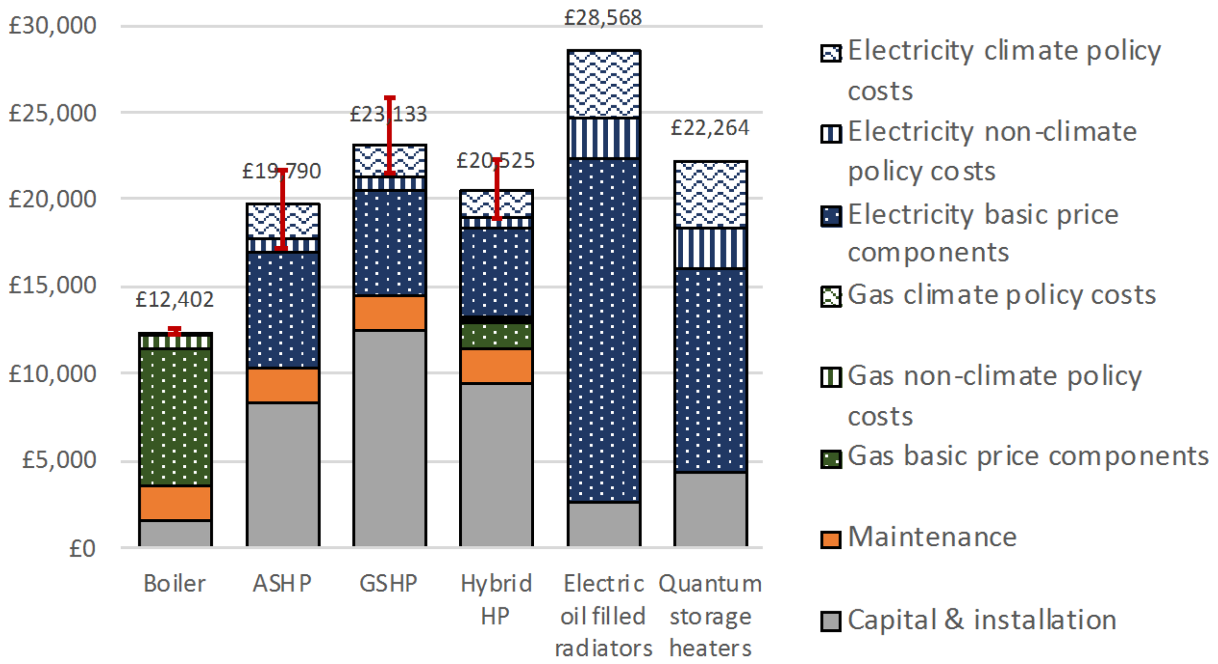

Figure 6: Net present cost of heating systems

(the red bars show the variation of cost with efficiency/SPFs, range of which is given in table 1, all other parameters remaining the same)

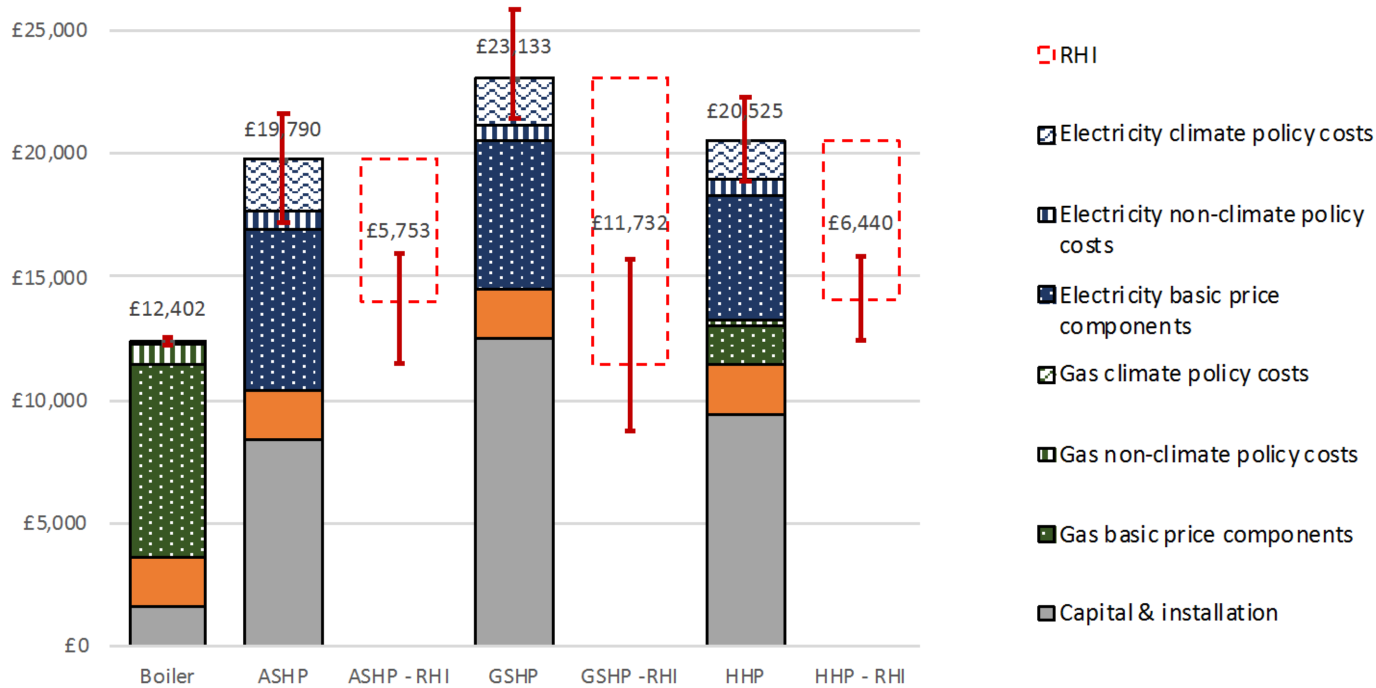

Figure 7: Net present cost of heating systems with RHI payments included (authors own calculations)

(the red bars show the variation of cost with efficiency/SPF, range of which is given in table 1, all other parameters remaining the same)

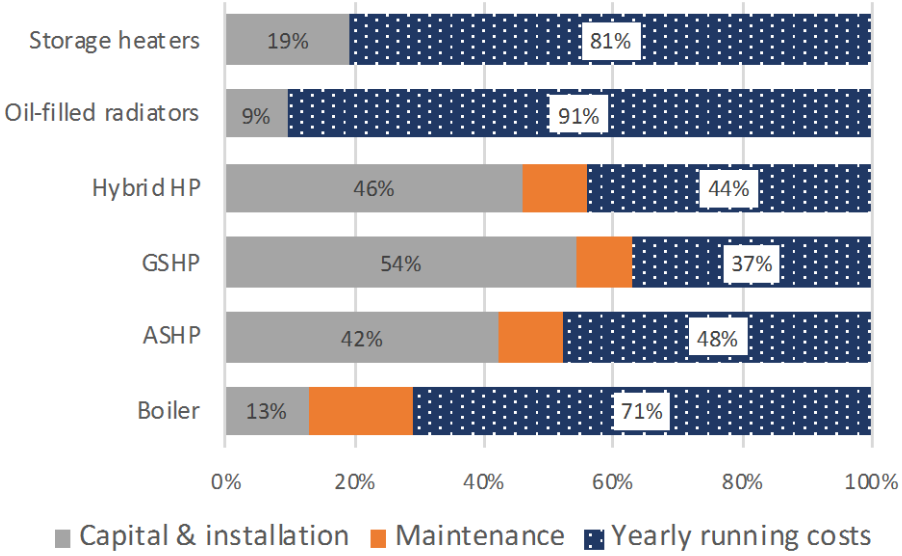

Figure 8: Breakdown of domestic heating system costs by upfront, maintenance, and yearly fuel costs