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Jobs, skills and regional implications of the low carbon residential heat transition in the UK

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A B S T R A C T

This paper investigates the regional employment implications of the projected UK heat pump rollout, emphasizing the availability of a skilled workforce as a crucial enabler. The UK labour market, however, faces persistent worker and skills shortages, posing delivery and cost challenges and triggering wage-cost pressures that could displace employment across the economy. This highlights an urgent policy need to understand not only the level, type, quality, and regional location of labour demand but also the drivers and potential mitigation strategies.

Using regional economic and workforce data, we map results from our dynamic economy-wide Computable General Equilibrium (CGE) model to provide new insights into the spatial distributional impacts of the UK heat pump rollout. Our findings indicate that net job creation is outpaced by real income gains, primarily driven by construction and manufacturing activities. Some regions exhibit lower relative job creation, partly due to rising labour costs affecting wage- and labour-intensive industries (e.g., finance, hospitality). Where energy efficiency gains from heat pump use translate to energy bill savings, the resulting boost to household spending power can help offset negative job impacts in consumer-facing sectors and host regions.

This novel integrated analysis makes a significant contribution by developing urgently needed, robust, and detailed evidence based on a strengthened understanding of the low-carbon heat labour and skills demands, while also considering critical factors such as labour mobility and competition. The produced insight and the proposed approach has the potential to be applicable to analyse other energy transitions.

1. Introduction

Heating buildings is the source of nearly a fifth of UK emissions (BEIS, 2022). Thus, meeting net zero targets will involve a low carbon heat transition, which is defined as the transition away from fossil fuel-based heat generation in buildings to low carbon alternatives (UK Government, 2021a). As part of the UK Government strategies to reduce emissions from buildings over the coming decades, electrification of heat, for example via heat pumps, is proposed as a key action in reducing emissions from homes where the majority of emissions are associated with boilers currently running on methane gas. The Heat and Buildings Strategy (UK Government, 2021a), highlights the importance of heat pumps to tackle this challenge, and sets out plans to deliver at least 600, 000 heat pump systems per year by 2028.

To achieve these targets, significant changes to the energy system - including the upgrade of the energy networks - will be needed, alongside the potential manufacturing and installation of new heating systems in residential properties. Here, a sufficiently large and skilled workforce will be a key enabler for these changes to happen, not only for the transition to low carbon heat, but for other net zero activities.

Understanding the jobs and skills requirements for the transition to net zero has been an area of considerable policy interest in recent years. In the recently published Powering up Britain (UK Government, 2023a) policy document, the UK Government sets out its ambition of seizing the economic benefits of the transition, in terms of jobs, productivity gains and economic growth, with an expectation that linked investment activity will support up to 480,000 jobs by 2030. Linked to this, the UK government's regional 'levelling-up' plans (UK Government, 2022) emphasises job creation as a key element in redistributing economic opportunities and prosperity across the UK. Devolved British nations have also set up specific just transition and jobs & skills development plans (Scottish Government, 2023).

The UK and other developed economies (e.g. the USA, or European Union), have identified the shortage of workers and skills as a critical challenge for net zero delivery (BCG, 2023). If not addressed, there is a real risk that net zero will not be achieved in time, costs will be inflated, and the opportunity to create decent sustainable jobs will be lost (Skidmore, 2023; Turner et al., 2022). Therefore, it is of key importance not only to understand the level and type of jobs needed, but also when and where these will be required, to help prepare communities and

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sectors and mitigate negative impacts.

Current literature tends to focus on the job creation or the skills implications linked to net zero activities, in particular on the transition to renewable energy generation, (Arvanitopoulos and Agnolucci, 2020; Bali Swain et al., 2022; Cai et al., 2014). There are also studies focusing on the transition to low carbon heat (Ram et al., 2022; Sovacool et al., 2023) but these are more limited. These and other studies in this area mostly focus on econometric, input-output models or multiplier approaches, and they pay little attention to regional impacts, or, when this is considered, it tends to be across very coarse geographical regions (i.e. country or continent level).

Other studies have developed empirical research on jobs and skills development policy, and potential regional implications (Briggs et al., 2022; Poulter et al., 2025; Zaussinger et al., 2025). These studies consider different methodologies, both quantitative and qualitative, including surveys, interviews and workshops, and provide useful insight in highlighting potential gaps in policy and modelling planning to develop the require workforce, while also identifying potential regional frictions. For example, the study by (Briggs et al., 2022), remarks on the barriers to building regional workforce for renewable energy in Australia, include the smaller size of regional labour markets, boom-bust cycles, high levels of labour utilisation and competition across inter-connected sectors in regional labour markets, in addition to other place-based socio-economic factors, such as the concentration of socially disadvantaged communities in under-employed populations and demographic changes, especially population ageing. However, wider economy implications and distributional impacts are not considered.

Furthermore, job creation and economic growth are not the only relevant metrics to understand and address jobs and skills challenges. As demand and competition for workers increase, labour supply constraints in economies like the UK are likely to create wage pressures and potential job losses in other sectors, including those not directly linked to net zero activities. Such wider labour market outcomes must be understood if stakeholders and policy makers are to make comprehensive plans to help people retrain and transfer skills, transitioning to new jobs. Again, much focus in studies to date has been on job creation and not necessarily on the potential for labour market displacement (Le Treut et al., 2021). Similarly, the quality of the jobs created is an area that is commonly overlooked (Bohlmann et al., 2019).

This paper, therefore, aims to fill up a very timely and policy pressing gap in the literature, developing an integrated approach that provides insight and address the following questions. How many jobs and what type of skills will be required to enable the transition to low carbon heat in the UK? In what timeframes and in which regions will these jobs manifest? Which sectors and regions are likely to suffer job displacement triggered by wage competition? What can we say about the quality of these jobs, in terms of income levels, and what are the likely just transition implications? To achieve this, we use an UK Computable General Equilibrium (CGE) economic model, UKENVI, to analyse the wider economy outcomes – including economic sector and household impacts, and labour market changes – driven by the transition of low carbon heat in the UK. CGE is a well-established peer-reviewed methodology, consistent with economic theory, and widely accepted and applied, including by UK Government, Scottish Government, and the European commission (Scottish Government, 2016; UK Government, 2014). Unlike previous studies and most sectoral analysis that examine issues in isolation, the whole-economy scope is a key CGE strength, critical to understand direct and indirect impacts across the whole economy, also allowing to analyse the effect of workforce mobility and competition (Turner et al., 2024).

Here, we refine UKENVI to analyse a heat electrification scenario where heat pumps become the main residential heating technology by 2050. We then analyse and map those employment and economic impacts to different UK regions, using available statistic data on UK workforce regional and sectoral distribution from the Office for National Statistics (ONS, 2022a). To the best of our knowledge, such integrated analysis, considering these key research questions around the regional jobs and skills implications of the residential heat decarbonisation has not been developed previously, and it provides a clear and significant contribution by developing urgently needed, robust, and detailed evidence based on a strengthened understanding of the low-carbon heat labour and skills demands. Also considering critical factors such as labour mobility and competition. Moreover, the proposed methodology has the potential to be used to analyse other energy transitions.

2. Methodology

2.1. *The UKENVI CGE model*

Our approach involves the development and use of the UKENVI computable general equilibrium (CGE) model (Alabi et al., 2022), with scenario information on investment spending requirements associated with heat pump deployment drawing on energy system modelling results generated using the UK TIMES model (Calvillo et al., 2023).

UKENVI covers all sectors and activities in the UK economy, here aggregated into 34 production sectors producing 34 commodities (see Appendix A). Our model is informed by a 2018 UK social accounting matrix (SAM), incorporating the most recently available UK industry-by-industry analytical input-output (IO) tables at the time of this study (ONS, 2022b). Assuming no other changes in the real economy, we take this SAM to be representative of the structure of the UK economy in our base year 2022 (year 0 in our simulations) and compare all results in all timeframes to this unchanging base. With a focus on isolating the economy-wide impacts driven by the switch from gas boilers to heat pumps in residential properties, we do not model any technological advancements or economic changes affecting the UK economy, during the timeframe modelled. Here we provide a brief overview of the most relevant characteristics and assumptions of the UKENVI model (detailed in Alabi et al., 2022).

2.1.1. *Labour market*

The labour force (sum of employed and unemployed workers) is fixed over time, with the starting unemployment rate set at 4.1% as reported by (ONS, 2023) and with no endogenous population growth. UKENVI does not include any skills or sector-specific competencies, meaning that we do not model skills endogenously and assume perfect mobility of workers across all sectors. We then take a first step in considering skills implications using the CGE model results in a separate exogenous analysis. Within UKENVI, we model a degree of imperfect competition, with the real take-home wage being determined using an econometrically-parameterised bargaining function, with power shifting between firms and workers depending on changes in the unemployment rate (Blanchflower and Oswald, 1989):

$$\ln(w_R) = \omega - \varepsilon \ln(u_t) \quad (1)$$

The parameter ε determines the relationship between wages and the unemployment rate and is set at 0.113 (Layard et al., 1991; Blanchflower and Oswald, 2005). However, as part of our sensitivity analyses, we also consider a labour market characterised by fixed real wages, where the nominal wages only adjust in line with the CPI. Finally, long-run conditions do not require that labour demand matches labour supply, thus, there can be long-run overall job gains or losses.

2.1.2. *Savings and investment*

Domestic savings rates are given as an exogenous share of household income. Investment is forward-looking, depending on exogenous depreciation and interest rates, set in extra-regional markets, and with quadratic adjustment costs. Thus, the actual capital stock of each sector gradually adjusts to its desired level, which is a function of sectoral output and relative input prices. Specifically, we follow Hayashi's (1982) treatment of investment, meaning that producers anticipate demands and prices across all timeframes, determining the optimal investment pattern to maximise the value of the firms. In long-run equilibrium, gross investment in each sector just covers capital depreciation.

2.1.3. Trade

We model the UK as a small open economy that trades with an exogenous rest of the world (ROW). Exports are sensitive to changes in relative domestic and foreign prices. All UK sectors and final consumers use a combination of domestically produced and imported commodities, which are assumed to be imperfect substitutes under an Armington (1969) assumption, imposed at commodity level. The initial price of foreign commodities effectively gives the model numeraire, and this price is fixed in all timeframes across all our scenarios.

2.1.4. Household consumption

Household disposable income (C), and therefore expenditure, is determined after deducting taxes ($HTAX$, $CTAX$) and savings (S, at a fixed rate) from household income.

$$C_{h,t} = Y_{h,t} - S_{h,t} - HTAX_{h,t} - CTAX_{h,t} - HPUMP_{h,t} \quad (2)$$

In our scenarios, the key drivers of changes in household real incomes and purchasing power are earnings from employment and taxes paid to government. Note that household income also includes income from capital and transfers, which are fixed in nominal terms and adjusted for changes in the CPI, from firms and the government. Households consume goods and services from each of the sectors in the model using a nested consumption function (i.e., in a similar manner to that in production) and are, therefore, sensitive to relative price changes between domestic outputs and imports.

A key assumption made here, is that any heat pumps purchase and installation costs that need to be met by the households precede any other consumption. These are represented by $HPUMP$ in (2), leading to direct restrictions to household's disposable income until the associated costs are fully met. We also note that any grants offered to support the installation of heat pumps are modelled as purpose-specific transfers to recipient households that have zero net impact on their disposable income.

2.1.5. Government

The government budget balance (GB) is determined as follows:

$$GB_t = GY_t - GEXP_t \quad (3)$$

Specifically for government expenditure ($GEXP$), we use the following equation:

$$GEXP_t = GQ_t \bullet Pg_t + TRG_{hh} \bullet CPI_t + TRG_{firm} \bullet CPI_t + \sum_h Grants_t \quad (4)$$

Government demand for goods and services (GQ) is fixed in real terms, with nominal expenditures adjusting to economy-wide price changes. Similarly, the transfers (TRG) to households and firms are fixed in real terms, with the nominal value adjusting to the CPI. In (4), there is a further exogenously determined parameter (Grants) which, as the name implies, represents the grants offered by the government to support the rollout of heat pumps.

The public budget is determined by a range of endogenous revenue sources, the sum of which give us the total government revenue (GY), and does not need to balance in the scenarios modelled here, allowing accumulation of public surpluses or deficits to inform wider fiscal modelling of decarbonisation actions. This is a deliberate decision as balancing the government budget would have implications of its own that would restrict our ability to identify the impacts directly driven by the heat pump rollout.

2.2. Scenario analysis approach

The overarching scenario assumption underpinning this analysis is that the full rollout of heat pumps needs to be concluded by 2050, steadily rolling out from 2022 over a 28-year period and with almost all heating to be low carbon by 2050 (around 65% using heat pumps[1]), as shown in Fig. 1. This is in line with the Future Energy Scenarios (FES) (National Grid, 2021) and the heat pump targets from the UK Government's Net Zero Strategy (UK Government, 2021b). Further details of this heat pump rollout and other technology assumptions can be found in Calvillo et al. (2023).

The scenario analysis will be developed in stages by broader type of economic activity, with the following considerations.

Stage 1. The electricity network will need to be upgraded to cope with the increased electricity demand

- We model, as a demand shock, the impact of the network upgrade until 2050 – a total spend of £21.1billion is required (from Calvillo et al., 2023) over a 28-year period.
- Of the total spending, 1/3 goes to UK Construction and the remainder 2/3 is imported.
- We deliberately abstract from considering how the network upgrade cost may be recovered. This is because the Great Britain's energy market regulator, Ofgem, has recently specified that efficiency gains should be achieved through the investment on the network, negating the need to increase the network charges in energy bills (Ofgem, 2022).

Stage 2. Purchase and installation of heat pumps[2]

- Drawing on Calvillo et al. (2023) TIMES analysis, we assume that over 10.2 million air source heat pumps need to be installed, at a total cost of £122.3billion.
- We assume an average cost of £11,960 (incl. VAT) per heat pump installation (of which £3680 is installation costs and the rest

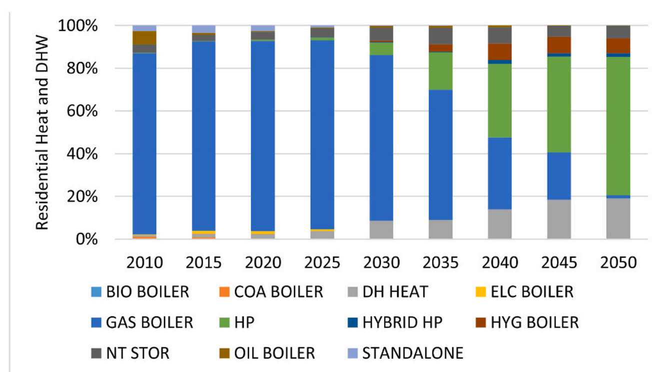

Fig. 1. Assumed technology changes and uptake for residential heat and domestic hot water production.

[1] This heat pump category considers both air-source and ground-source systems. The technologies considered in this scenario pathway are: biogas (BIO) and natural gas boilers, electric night storage (NT STOR), coal (COA) and oil (OIL) boilers, heat pumps (HP), district heating (DH), hybrid heat pump systems (HYBRID HP), standalone electric heaters (STANDALONE), electric (ELC) or hydrogen (HYG) boilers. See Calvillo et al. (2023) for further detail on the technical parameters considered.

[2] Here, to isolate the economic impacts of the expected heat pump rollout, we focus solely on heat pump installations and the required ancillary equipment (e.g. pipework, water tanks, radiators, etc.), but we do not consider any energy efficiency (i.e. building retrofitting) installations. We have explored the potential wider economy benefits of energy efficiency on a separate work: https://doi.org/10.1016/j.enpol.2021.112375.

involves the heat pump system and ancillary equipment), based on rough costings reported by Delta energy & environment report for BEIS (2020a) - only 25% of heat pumps to be sourced in the UK.[3]

- On the other hand, 100% of installation work is carried out by the (broad) UK Construction sector, involving UK-based workers.
- Costs are assumed to be covered by households via 10 years interest-free loans (where loan finance is likely to be the dominant finance model for heat pump installation in the UK, but where the role of things like partial government grants should be the focus of further applied analysis as the policy landscape further develops).

Stage 3. Heat pump use, replacing gas fuelled heating with a more efficient system, reducing household energy use

- We consider the impacts on households of using heat pumps rather than gas-fired boilers, which are driven by physical energy efficiency gains in operating heating systems, set in the context of different assumptions about the relative monetary price of electricity versus gas.

Heat pumps require less units of energy to produce the same heating output. This increased system efficiency can translate to around 40% less residential energy use (based on findings from Calvillo et al. (2023), assuming a coefficient of performance (COP) of 2.52).[4] However, the price difference between electricity and gas has a defining role in translating or not the energy use savings into monetary savings (Turner et al., 2023), where high electricity prices relative to gas may offset any cost savings, while similar electricity-gas prices can result in important bill savings to households. Under Stage 3, we analyse here three electricity:gas price ratios.

- 1:1, assuming a theoretical parity between electricity and gas prices, where all the energy use savings translate into household energy bills savings;
- 3.3:1, which reflect the electricity:gas price ratio experienced by UK households from the Energy Price Guarantee (UK Government, 2023b), effective Oct 2022 to June 2023;
- 4.8:1, reflecting the electricity:gas price ratio (informed by the 2020 prices) traditionally experienced by households, before the most recent energy price shocks (Ofgem, 2020).

Stage 4. Integrating stages 1–3: network upgrades, heat pump installation and use (under the 3.3:1 price ratio)

- Analysing the combined economic impacts of the different heat pump rollout activities: network upgrades, purchase and installation of heat pumps, and heat pump use.
- We selected the 3.3:1 price ratio for this heat pump use case (effective Oct 2022 to June 2023), as it was at the time of preparing this paper, the most current price differential for the UK.

See also Appendix C for a summary of scenario parameters.

2.3. Employment impacts regional mapping approach

The economic analysis developed with our CGE model provides important information on the level of jobs required and the sectoral implications for the transition to low carbon heat. However, as this is a national level model, the data it uses, as well as the specific scenarios modelled, are focusing on the UK as a whole, rather than different regions within the UK. As a result, the model outputs do not directly provide information of regional impacts. Thus, a necessary assumption is that the heat pump rollout, for instance, follows the distribution of the population across the UK.

Understanding what types of jobs are required, when and where, is of key importance in order to prepare for the effective heat pump rollout, making sure that adequate skills and workforce is available where and when is needed.

We take the employment and economic data from our CGE model, following the scenario analysis approach described in Section 2.2, and we analyse the regional distribution of these results in two main categories.

- Employment changes, in terms of number of jobs and sector
- Quality of jobs, in terms of changes on nominal income from employment

Our regional mapping of employment impacts is based on primary and secondary data processing and analysis, consisting of the following tasks.

- Take employment and economic impacts data from CGE results.
- Map those impacts to different regions, using ONS available data 'Workforce jobs by region and industry' (ONS, 2022a)
  1. Aggregate economic sectors from CGE model to match ONS data sectors, which are based on the broad UK Standard Industrial Classification (SIC) groups (See Appendix B for the detail on the sector aggregation and matching)
  2. Calculate current proportion of jobs across industries and regions (from ONS data, 2022 values) – for example, the percentage of construction jobs in each region.
  3. Map CGE labour changes to breakdown calculated in (2). In other words, new job changes are distributed across the different regions, based on the proportions calculated from the ONS data.

Fig. 2 shows an example of the mapping approach (construction sector jobs changes).

3. Results and discussion

3.1. Economic analysis results

Fig. 3 shows some key macroeconomic outcomes from our CGE model resulting from the simulated heat pump rollout in the UK across the different scenario stages set out in Section 2.2. The results indicate that there is a close relationship between the household spending, the economy-wide prices (reflected by the CPI) and the overall level of economic activity, reflected by the GDP. At the timeframes of significant network upgrade and/or heat pump manufacturing and installation activity, the creation of jobs in the associated sectors contributes towards pushing wages, the households' income from employment and spending upwards. This introduces upward pressures to the prices across the economy. However, the importance of household spending in driving increases in economy-wide prices is more clear in Fig. 3b and Fig. 3e, where restrictions in household spending ultimately lead to a drop in the CPI.

Impacts on costs and prices across the economy are particularly important as they influence the competitiveness of UK industries in domestic and international markets and, thus, play a key role on the

[3] This 25% UK manufacturing assumption was developed and tested with stakeholders, and roughly aligns with reported values available in the literature (BEIS, 2020b). In future work, we will explore the economic implications of high shares of UK manufacturing.

[4] We assume a conservative seasonal average COP of 2.52 for this analysis, based on an air source heat pump system. Which is also the basis of the modelling analysis in Calvillo et al. (2023), as the UK TIMES model tends to favour air-source due to lower costs. We developed a sensitivity analysis on this parameter (not reported here), also considering COPs of 2.8, 3.2 and 3.5. The greater COPs drive bigger energy savings, reaching 46% savings in overall residential energy use by 2050, relative to the baseline. However, the differences on the macroeconomic outcomes of this slightly greater energy savings are relatively small and do not affect the findings, in qualitative terms, and key messages reported in this paper.

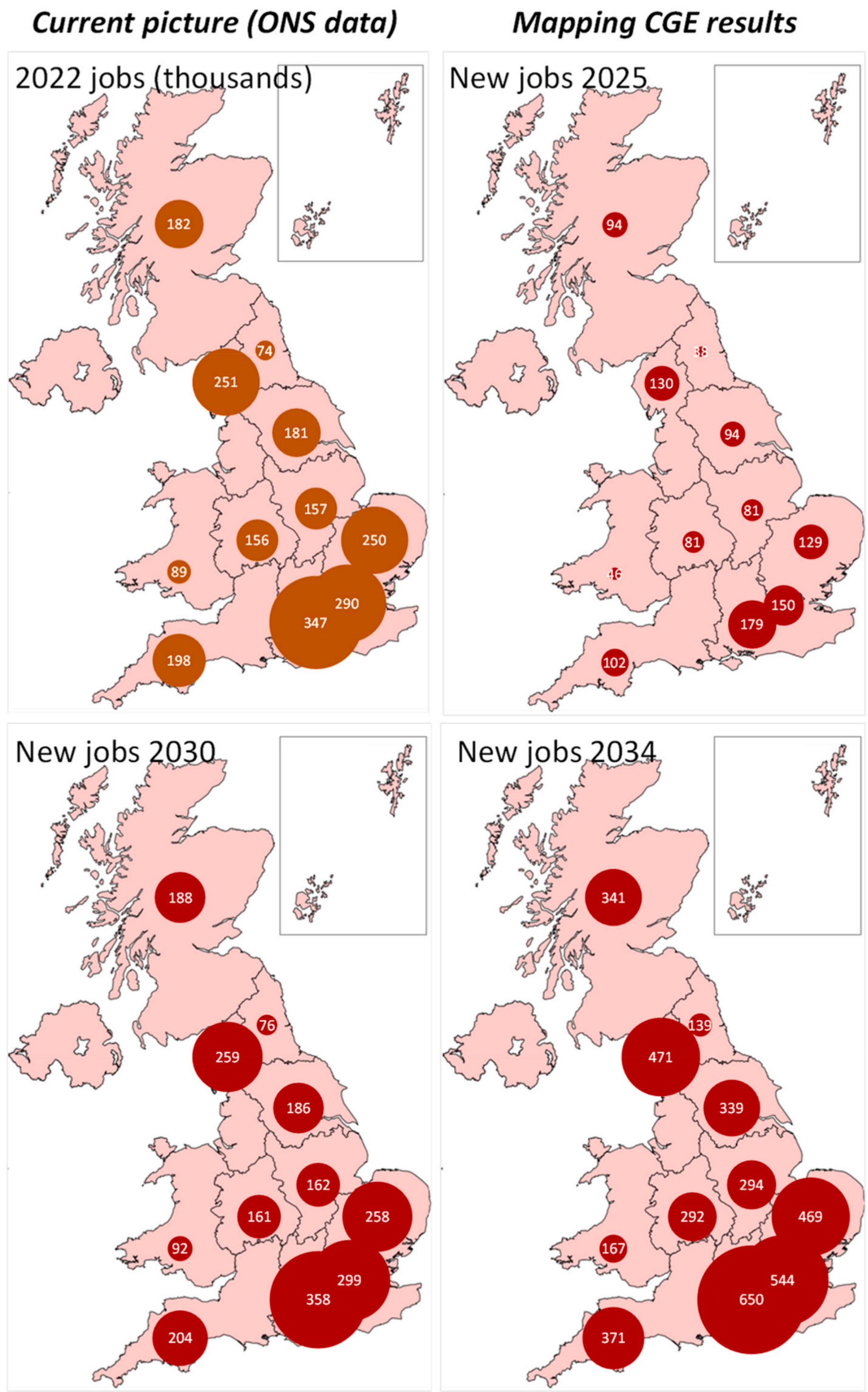

Fig. 2. Example of mapping: Jobs changes in construction sector (Stage 1 – network upgrades).

employment requirements across the different sectors. Fig. 4 shows the sectoral employment changes (in number of full-time equivalent FTE jobs). Here we show changes at year 2033, relative to base year. This year has been selected as it is the year where peak economic activity takes place for most of analysed scenarios, and therefore it is used across our economic and regional impact analysis to assess the scale of changes (see Section 3.2). However, our analysis extends across the dynamic adjustment of employment and other variables.

3.1.1. *Stage 1 – electricity network upgrades*

The network upgrade activity (Fig. 3a), presents a positive, but transitory, demand shock on the UK economy. Here, the boost to the UK Construction industry through its role in expanding electricity network capacity triggers positive multiplier effects in economic outputs. These ripple through upstream supply chains, constrained by cost and price impacts particularly in the presence of the national labour supply constraint. Thus, there is a transitory uplift in GDP, employment and household spending (Fig. 3a). Note that the uplift in household expenditure is proportionately greater than that in GDP in all timeframes. One

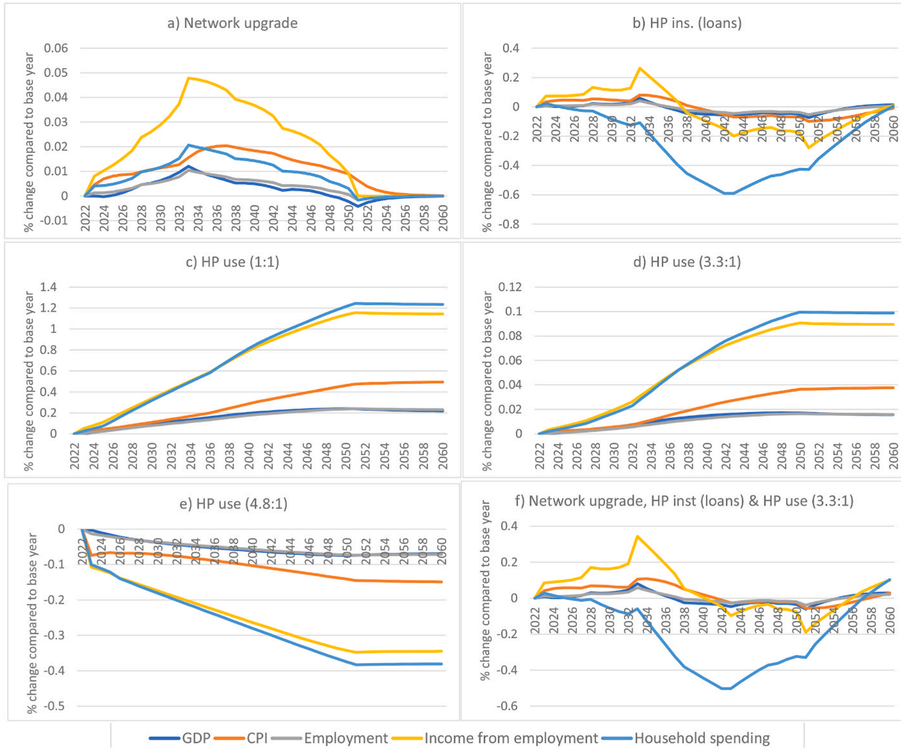

Fig. 3. Evolution of key macroeconomic variables for the different stages linked to the heat pump rollout in the UK.

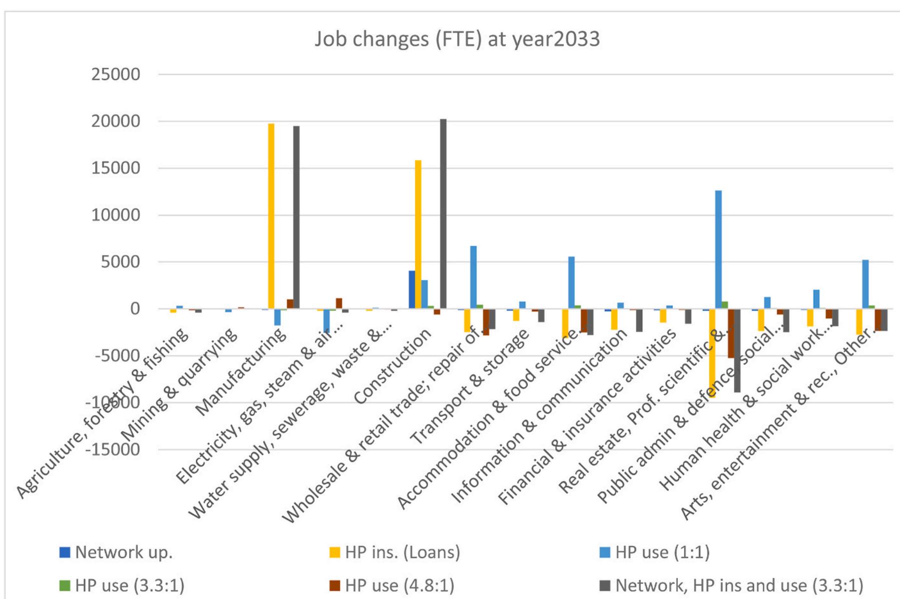

Fig. 4. Sectoral employment changes (FTE) at year 2033 (peak activity year) relative to baseline.

of the factors for this is the disposable household income, and the uplift here is driven by increased income from employment as labour demand and the wages both rise (the latter peaking at almost a 0.05% increase in 2033).

On the other hand, the increase in labour demand associated with spending on electricity network upgrades, triggers a real wage bargaining process, as unemployment falls, that has cost and price implications that ripple out across the UK economy. Crucially, the output effects of higher labour costs and associated price pressures act to constrain employment gains in expanding sectors (including 'Construction', as the biggest direct beneficiary here), with some sectors suffering net losses in employment (reported in Fig. 4). Furthermore, the additional consumption demand by households introduces upward price pressures of its own that act to cushion the potential economy-wide gains associated with the network upgrade activity.

3.1.2. *Stage 2 – Heat pump manufacturing and installation*

Fig. 3b shows the economic outcomes of deploying, manufacturing and installing heat pumps. Here we assume that the purchase and installation costs are paid by households via loans. For this, we simplify by abstracting from any interest or other associated finance costs. We assume the loan repayments precede any other use of post-tax income, thereby introducing a direct constraint on household spending on other goods and services.

From Fig. 3b, we can see that households heat pumps loan repayments (10 years for each household, with more households joining the process every year), imposes restrictions on disposable income to spend on other goods and services. Moreover, as a significant share of the heat pumps is sourced outside the UK, the household spending on heat pump is effectively reducing the overall household consumption of domestically produced goods and services. As a result, we observe temporary GDP losses in some timeframes. This also highlights the role of the funding mechanism in determining the timing in which certain impacts may materialise.

The loans option relieves some of the pressure on household incomes in the early years, allowing GDP gains to be materialise in these time periods. However, loan repayment requirements grow over time as more households adopt heat pumps, reaching the maximum level of payments by year 20 (2042). By that point the installation activity is reduced and the value-added generated by the manufacturing and installation of heat pumps is not sufficient to offset the lost value-added due to reduced non-heat pump consumption. This drives job losses in non-heat pump related sectors (see Fig. 4), despite the fall in economy-wide prices that acts to restore some of the lost competitiveness of the UK sectors in the previous years. Hence, we observe some GDP losses that can exceed the ones driven by the outright payments and, crucially, may be present beyond the end of the installation activity and until the loans are fully repaid.

3.1.3. Stage 3 – Heat pump use under different electricity:gas price differentials

The key difference at this stage is that the impacts observed are exclusively attributable to the changes in household spending to run heating systems and what this means for consumption of other goods and services. Thus, the crucial driver of the wider economy impacts at this stage is whether, and to what extent, the physical energy savings from switching from gas boilers to heat pumps will translate to energy bills savings, freeing up spending (or not) for other purposes. Fig. 3c d.e summarise key macroeconomic impacts under different electricity and gas price ratios.

Starting with an illustrative the '1:1' case (Fig. 3c), no price differential between electricity and gas, thereby enabling the full energy efficiency gains of heat pumps to be realised. Here, our results show that by freeing up some of the households' disposable income it is possible to markedly stimulate the wider UK economy. This is reflected in the maximum, 0.216% (£3.8billion) sustained GDP gain we find here. This also drives a net sustained increase in employment of 67,247 full-time equivalent (FTE) jobs (+0.23% compared to the base year). These outcomes suggest that reduced energy bills are indeed a driver of sustained economy-wide gains. As in the previous cases, however, increased labour demand (and the consequent drop in the unemployment rate under a constrained labour supply) drives the real, and by extension the nominal wage, rate upwards, increasing the labour cost for UK industries and therefore the output prices.

However, the 1:1 case is not in any way realistic. Electricity has historically been higher priced per unit than gas in the UK, where official data for the UK suggest that by the end of 2020, electricity was 4.8 times more expensive than gas (Ofgem, 2020). This significant price difference means that the heat pumps energy savings are completely eroded when it comes to energy bills. Effectively, under the 4.8:1 case, households could face 8.16% higher energy bills, in the absence of other energy efficiency improvement measures. As a result of the contractionary pressure of the resulting drop in total consumer spending, we observe long-run GDP losses of −0.069% (-£1.2billion) and 20,844 less FTE jobs, mainly due to a reduction of −0.38% in household consumption (see Fig. 3e and Fig. 4). It is clear then that whether there will be economy-wide benefits, alongside the physical/environmental benefits achieved by using heat pumps, depends crucially on the electricity and gas price differential.

Interestingly, the 2022 energy price shock has led the UK Government to freeze the prices of gas and electricity effective of October 2022. This Energy Price Guarantee (EPG) narrowed the gap between the electricity and gas prices to '3.3 to 1', due to the significantly higher increase in the gas price compared to the price of electricity (UK Government, 2023b). Despite introducing a number of social challenges in relation to fuel poverty and the wider cost-of-living crisis, this change in the electricity and gas price differential also meant that the use of heat pumps would now reduce the households' energy bills by 2.3%. This reduction is considerably smaller than the one discussed for the illustrative 1:1 case. Thus, the economy-wide outcomes are expected to be positive, but smaller in scale that in the illustrative case. See Fig. 3d.

3.1.4. Stage 4 – integrating stages 1–3: network upgrades, heat pump installation and use (under the 3.3:1 price ratio)

If we then simulate stages 1–3 simultaneously, the outcome is a very mixed picture in term impacts on prices, wages, GDP and by extension other key variables of policy interest such as employment. As we've observed already, upgrading the electricity network delivers generally favourable outcomes, while the upgrade activity takes place. On the other hand, the combination of manufacturing, installing and rolling out heat pumps can drive some negative economy-wide outcomes as the loan repayment requirements start accumulating. This raises the question then whether, and to what extent, can any energy bills savings driven by the use of heat pumps help ensure net positive outcomes overall in all timeframes?

The main determinant of the outcomes emerging (see Fig. 3f) is the impact of those enabling stage activities on household consumption. In the period between 2023 and 2037, the activity associated with the network upgrade (stage 1) along with the gains emerging from the use of heat pumps (stage 3), help deliver better economy-wide outcomes compared to the heat pump installation alone (stage 2), to the point that some negative impacts on GDP, employment and nominal income between 2038 and 2041 are avoided. However, beyond that point, the economic outcomes follow a similar trend as those shown for stage 2, where the significant restrictions imposed by loan repayments to household consumption cannot be offset by the limited spending directed to the UK economy.

Nonetheless, the real household consumption levels remain above what we observe for stage 2 in isolation. A key driving factor is the fact that employment outcomes improve across all timeframes relative to those of stage 2 alone. The network upgrade triggers employment gains until 2050, while employment benefits are supported over a longer timeframe due to the real income impacts of energy bills savings achieved through the use of heat pumps. The higher levels of employment also drive higher nominal wage rates compared to stage 2 alone, which, while adding to producer costs, means that nominal income from employment is boosted across all timeframes. This helps households retain some of their consumption, even in the presence of loan repayments and increased economy-wide prices (reflected by the CPI), which combine to impact real disposable income. This result highlights the role of energy bills savings (even if these are small in the 3.3:1 price ratio) as a route to mitigating the negative impacts of other elements of the heat pump deployment process, which include increases in general price levels. Crucially, recovery of domestic consumer spending power helps mitigate job losses in labour intensive sectors, such as services, hospitality, retail, etc. as costs and prices rise across the economy. However, the net outcomes in different sectors could have important regional implications, where local economies will be more reliant on some sectors.

Thus, here we extend our economic analysis here by developing our regional employment impact mapping and analysis in Section 3.2, with the aim of further understanding the implications and feasibility of job creation, and to analyse the potential impacts of job displacement and skills requirements across communities.

3.2. Regional employment impact mapping and analysis

Fig. 5 shows the regional mapping of employment changes on year 2033 (peak activity year), emphasizing the key sectors where most employment changes take place. For example, the construction and manufacturing sectors for the network upgrade and heat pump installation activities.

Fig. 6 shows the regional mapping of employment changes with aggregated sectors, showing the evolution of changes for years 2025–2050. This figure also shows the baseline regional employment data, taken from (ONS, 2022a), for reference (dotted line on figure, right hand side vertical axis). See Section 2.3 for detailed description of the regional mapping methodology.

Fig. 7 shows the regional mapping of relative income and employment changes on year 2033 (peak activity year), expressed as % of change relative to the base year. We have taken the changes on income from employment as a way to assess changes in quality of employment (i.e. better paid jobs).[5]

3.2.1. Stage 1 – electricity network upgrades

Fig. 5a and Fig. 6a show the employment changes linked to the economic activity of upgrading the electricity networks to accommodate the increased electric demand from the heat pump rollout in the UK. This network upgrade activity is mostly linked to the construction sector, where most of the changes concentrate. We see that construction job creation varies across the regions, with large pockets of construction job creation is concentrated in more densely populated areas (see Fig. 5a). This is to be expected, given that the construction activity will include the distribution network which is denser in largely populated areas (such as London, the Southeast and East of England).

Looking at the aggregated employment changes (all sectors) in Fig. 6a, we can see the evolution of employment changes linked to the network upgrading activity, peaking at 2033. Once the networks upgrade is completed, the activity winds up, so the long run employment changes (2050) are more modest. Comparing net job creation with the baseline regional jobs (blue dotted line in the figure), it can be seen that most regions follow similar trends to the ones before the network upgrade. However, London is significantly lagging in terms of net job creation (new construction jobs is offset by losses in other sectors), based on historic trends. This is indicative of the proportion of construction jobs to other employment, where increasing labour costs, due to wage pressures from increased labour demand in construction, negatively affect employment in many labour-intensive industries (e.g., finance, consultancies, hospitality etc.). The composition of employment in London consists more of these type of jobs – therefore net employment does not improve as in other regions.

Looking at changes in income in contrast of job number for the network upgrade (Fig. 7a), the relative changes for this activity are modest. However, incomes in percentage terms, are increasing around 4 times more rapidly than job increases, across all regions (around 0.04 % income change vs around 0.01% job changes). Most new employment opportunities are located in sectors paying less than the median wage (primarily construction), but also job losses occur to labour intensive but lower paid sectors. This result also suggests that if the cost of heat pump rollout activity is not passed directly to households (in this case network upgrade), then the broader economic outcomes lead to a more than proportional increase of income from employment, indicating an improvement of the quality of jobs.

[5] We understand that income from employment is one way to assess job quality, but there are other indicators that provide insight on the quality of employment (see (ONS, 2022c)). However, these fall outside the scope of this paper.

3.2.2. Stage 2 – Heat pump manufacturing and installation

Fig. 5b and Fig. 6b show the employment changes linked to manufacturing and installation of heat pumps, here considering the likely central repayment methods of interest free loans. Here, the economic activity is mostly linked to the construction and manufacturing sectors, where most of the changes concentrate. The distribution of jobs differs across regions, reflecting on the local economies. For instance, the Midlands, Yorkshire and the Humber, and North West regions show greater job creation in manufacturing (around 2400 new jobs in 2033) than in the construction sector (around 1300 new jobs). The opposite is true for London, who has a comparatively lower manufacturing presence (around 1000 jobs) in the local economy than construction (around 2100 jobs).

The losses in other sectors, driven by restrictions on household disposable income from heat pump repayments, offset any gains in manufacturing and construction for some of the regions. For example, London is hit harder with over 4000 net jobs lost (see Fig. 6b), as households spend less on hospitality and other services, which are some of the key sector activities in London.

Fig. 7b show the percentage of income and employment changes for this stage. Here we see that the broader economic outcomes lead to a more than proportional increase of income from employment (around 0.2% income increase vs 0.05% job numbers increase), indicating an improvement of the quality of jobs.

Moreover, there are examples of improved job quality at the regional level. For instance, in Scotland, heat pump installation leads to a net reduction of employment beyond the construction/manufacturing activity, but there is still a substantial increase in nominal income from employment. This is linked to wider increase in nominal wages but also increased employment opportunities in sectors that typically offer higher wages (e.g., manufacturing or mining support). However, the differences between regions persist, while at the same time any price increases due to broadly higher wage rates are likely to be of comparable size across the economy, but there is potential for the real disposable income of households to be affected more in the regions that experience smaller nominal income gains.

3.2.3. Stage 3 – Heat pump use under different electricity:gas price differentials

Figs. 5 and 6 show the employment changes linked to the use of heat pumps, under the electricity:gas price ratios of 1:1 (c), 3.3:1 (d) and 4.8:1 (e), (see Section 2.2 for further details on the price ratio scenarios).

Positive impacts linked to the heat pump use are driven by higher household consumption from energy cost savings (see 1:1 ratio in Fig. 5c and Fig. 6c), with most sectors observing employment gains. In particular, the sectors of real estate, professional scientific & technical services, and admin. & support service activities, showing the bigger job gains of around 400 to 3000, depending on the region. However, there are relatively small losses in electricity and gas sectors[6] driven by the lower fuel household consumption (less energy and at a lower cost in this case). Also, manufacturing show losses driven by wider economic effects, such as wage and price pressures: if a sector is very labour intensive but not linked to household consumption then despite the households consuming more, the sector will not benefit while also suffering from the increased labour cost from increased household consumption. The point here is that even when the economy as a whole grows, normally not all sectors benefit and it is possible to see crowding out effects.

Again, the relative price difference between electricity and gas a big controlling factor. Negative employment impacts appear more widely with constrained household income due to higher energy bills in the 4.8:1 case (see Fig. 6e, where London sees the greater net job losses of

[6] These sectors are aggregated in our analysis, see appendix A for details on the aggregation.

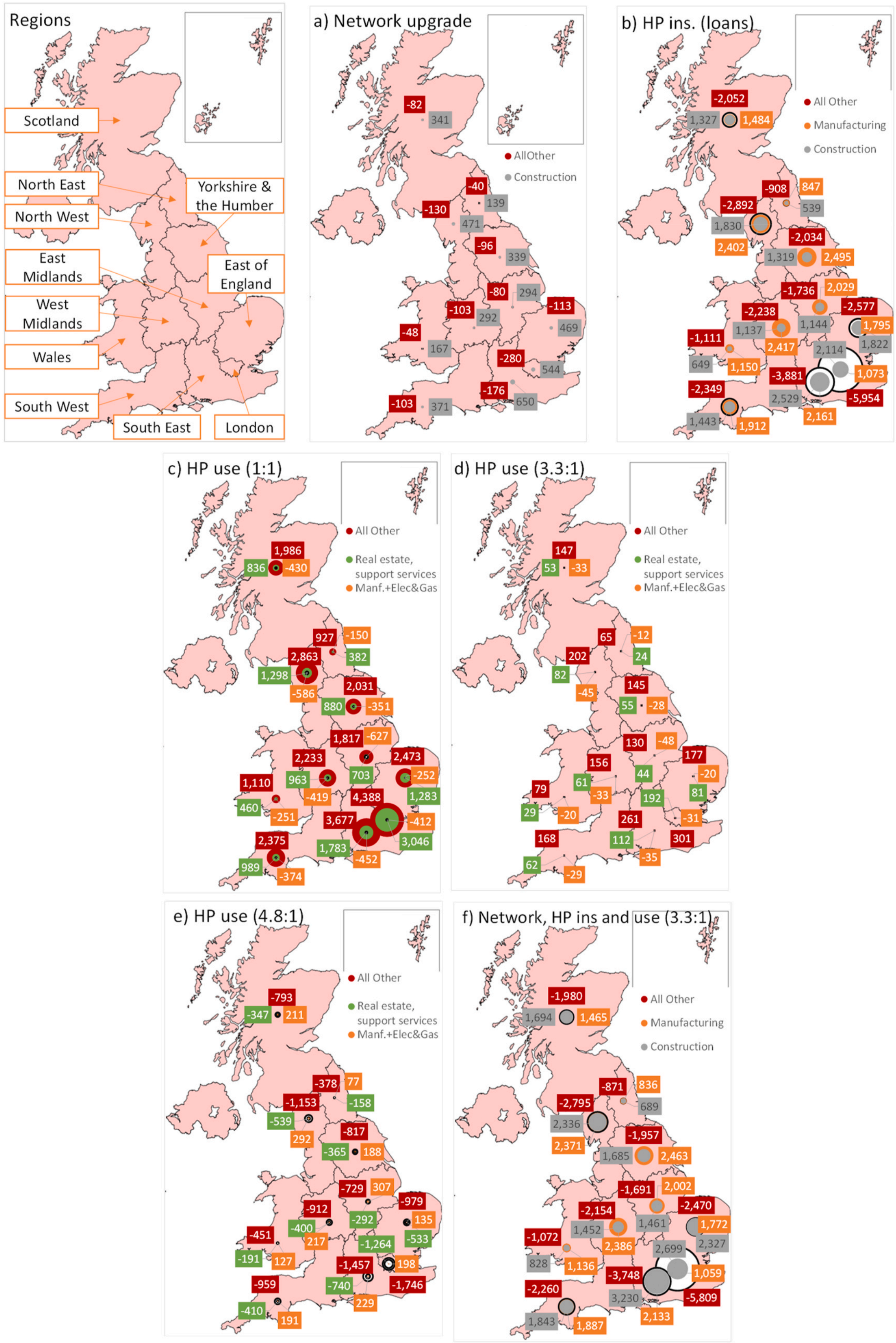

Fig. 5. Regional employment changes (FTE) at year 2033 (peak activity year) relative to baseline – focus on key activity sectors.

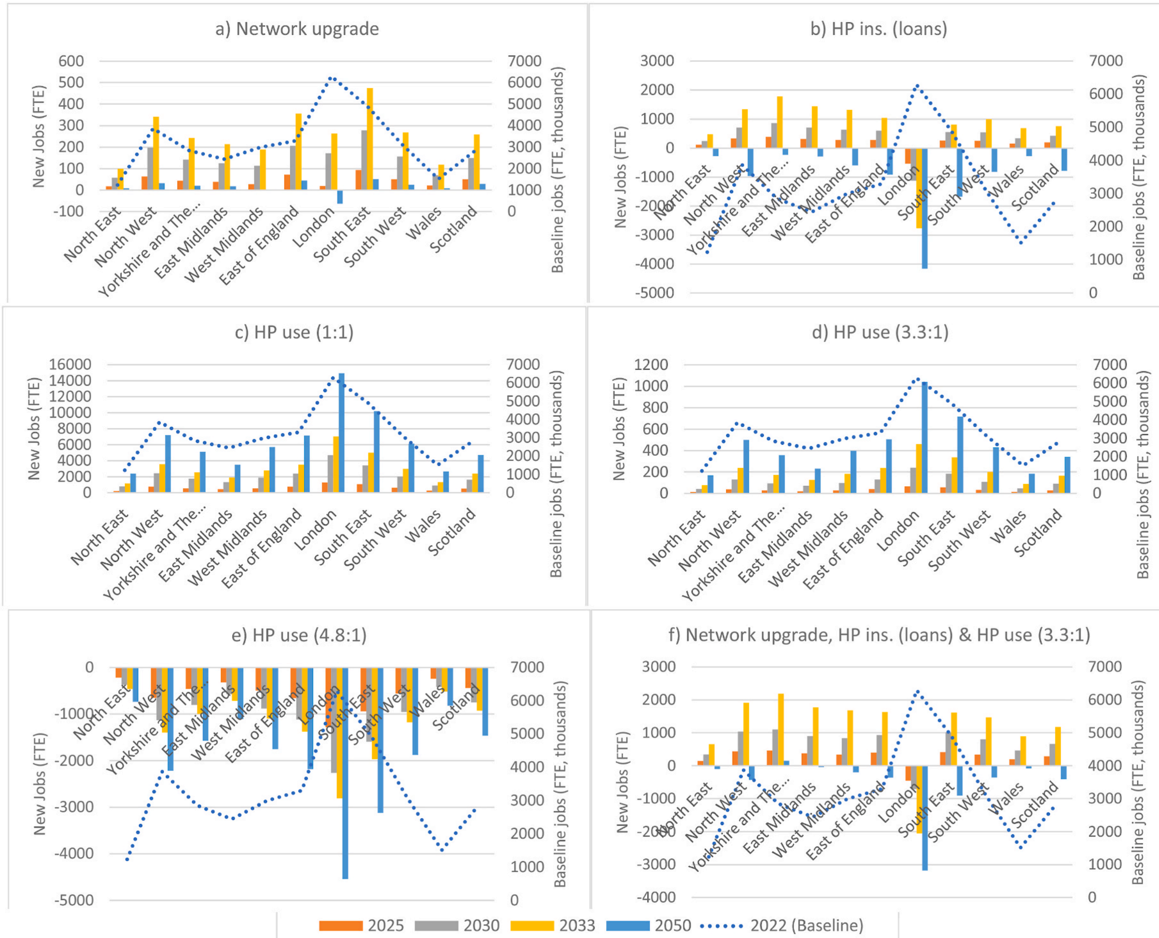

Fig. 6. Regional employment changes (FTE) relative to baseline, years 2025–2050 – all sectors aggregated.

over 4500 by 2050).

Looking at regional impacts, we observe differences with more job creation (or potential losses) in larger residential centres, linked to more heat pumps installed, driving greater household income gains. This in turn drive more household consumption across the economy and jobs created. Here, London and the Southeast outperform all the other regions (over 14000 and 10000 net job gains, respectively; see Fig. 6c). These results show on the one hand, the importance of the price difference between electricity and gas, to translate energy use savings into cost savings to households. The employment gains in these cases can help offset losses from heat pump installation costs. On the other hand, the employment gains from heat pumps use tend to favour the southern UK regions, including London, which have historically hosted larger number of jobs and economic growth, whereas other less prosperous regions do not benefit as much. This suggest policy implications to the UK Government levelling up agenda (UK Government, 2022).

We can see a similar picture with the relative changes on income vs job numbers (Fig. 7), with a more than proportional increase of income from employment arises in the 1:1 price ratio, indicating an improvement of the quality of jobs (Fig. 7c).

3.2.4. Stage 4 – integrating stages 1–3: network upgrades, heat pump installation and use (under the 3.3:1 price ratio)

Fig. 5f, Fig. 6f and Fig. 7f shows the results of the case integrating stages 1, 2, and 3. That is, simulating jointly the network upgrades, the heat pump manufacturing and installation activities and the heat pump use, under the 3.3:1 price ratio. The results from the figures are representative of the findings described in the previous sections. There is a clear increase in demand for labour in manufacturing and construction activities, but this demand is partially, or even fully, met by labour losses in other sectors and/or other regions. For instance, in London there are over 3700 additional FTE jobs in Construction and Manufacturing, but over 5800 FTE job losses in all other sectors. On the other hand, in Scotland, the jobs created in Construction and Manufacturing are over 3,000, while the jobs lost are just under 2000. There is a clear discrepancy then between different regions in terms of the overall implications in total employment, as indicated by Fig. 6f.

However, the picture is different when considering the quality of employment (see Fig. 7f). Indeed, there are still variations between the regions, but a common outcome is the proportionately higher increase of income from employment compared to the employment itself. This suggest the shift towards jobs paying above the UK median wage and the overall increase in nominal wage rates triggered by the substantial demand for workers. In this process, the use of heat pumps is also beneficial as the energy bills savings they enable, leads to greater levels of household consumption compared to the combination of the network upgrade and the heat pump manufacturing and installation activities. This helps the retention and/or expansion of employment in tertiary sectors, which tend to be around the UK median wage or above, while also supporting a greater increase in the nominal wage rates.

3.2.5. Sensitivity analysis: impact of heat pump repayment mechanisms and wage bargaining process

To assess the robustness of our findings and explore alternative policy design considerations, we conduct sensitivity analyses on two key assumptions: (1) the wage setting mode underpinning labour market dynamics, and (2) the methods for financing heat pump installations. These analyses aim to quantify how deviations from our baseline

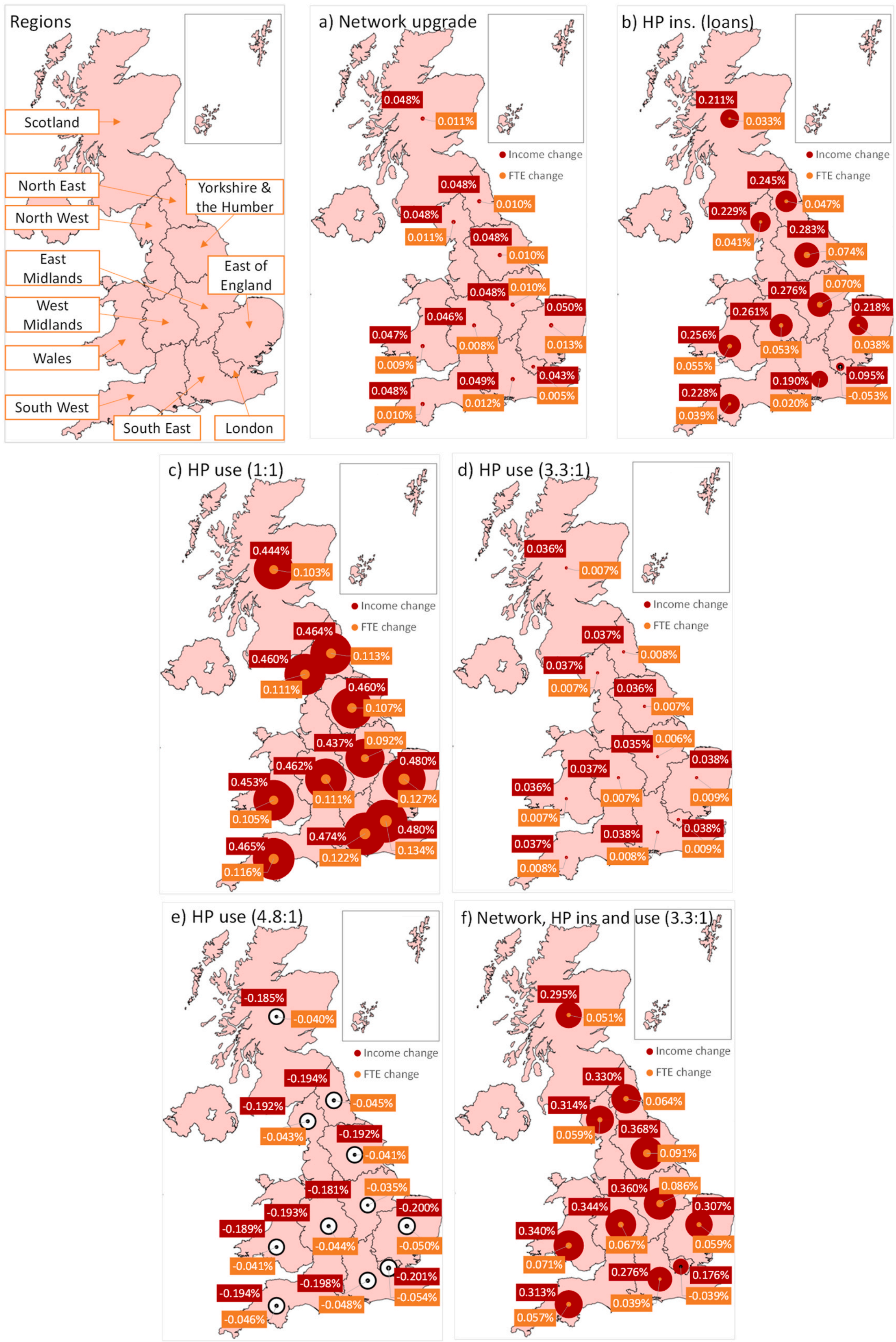

Fig. 7. Regional relative income (%£) and employment (%FTE) changes at year 2033 (peak activity year) relative to baseline.

assumptions might alter employment and wider economy outcomes.

3.2.5.1. Wage bargaining vs fixed wage (stage 2, loans). As discussed in Section 2.1, our default modelling assumes bargained real wages (BRW) adjusting via a process influenced by unemployment rates. Fig. 8 compares this to a fixed real wage (FRW) case, where labour costs only adjust to economy-wide prices rather than changes in labour demand. Under FRW, the absence of significant wage-driven price pressures largely flattens consumer price index (CPI) growth, enabling higher GDP and employment peaks (+0.12% relative than baseline) in 2033. However, the lack of wage flexibility introduces greater longer-term losses when transitioning towards the repayment of loans: post-2040, GDP and employment decline more sharply (−0.13%).

This reflects the dual role of BRW in cushioning both the potential economy-wide gains and any emerging economy-wide losses. On the other hand, under FRW any economy-wide price pressures are initially suppressed, boosting sectoral hiring capacity and improving the economy-wide outcomes. However, in subsequent timeframes, where the rollout activity has ended but households are still repaying their loans, a FRW setup means that workers are not willing to accept smaller wages to keep their jobs, hence removing the cushioning effect of a BRW and exacerbating the economic contraction until the loan repayment has largely concluded.

3.2.5.2. Heat pump repayment methods: upfront payment, loans or grants (stage 2). In terms of financing mechanisms for heat pump installations, we evaluate other two methods compared with the central case. All of these methods are listed below.

1. **Loans** (baseline): 10-year interest-free repayments, as modelled in Section 3.1.2.
2. **Household pays**: Households bear full costs immediately, sharply reducing their disposable income.
3. **Grants**: Government fully subsidises installations without offsetting fiscal measures (e.g., taxation or spending cuts).

In the household pays case, Fig. 9a, upfront payments induce much steeper initial GDP contractions (−0.59%), as households prioritise heat pump costs over any other consumption. This exacerbates job losses in consumer-facing sectors. In comparison, while deferring economic impacts via loans (Fig. 9b) mitigates short-term consumption shocks associated with heat pump purchase and installation, comparable temporary negative economy-wide changes manifest in later periods, where there is no heat pump rollout activity present to offset the impacts from the restrictions on household disposable income imposed by loans. This highlights the importance of temporal cost distribution in policy design.

Grants (Fig. 9c), conversely, eliminate household repayment burdens, sustaining disposable income and delivering modest GDP growth (0.17% by 2033). However, it should be noted that the results in Fig. 9c are likely to change depending on how the government opts to raise the necessary funding for the grants. The limitation faced by this work is that there are no clear policy indications to inform a relevant analysis. In the absence of relevant information, we can only turn to broad approaches such as adjustments to the income tax rate or the government consumption. We opt to abstract from said considerations as they would skew the results, making it challenging to isolate the impacts driven by the heat pump rollout, while they would not contribute significantly to the existing literature.

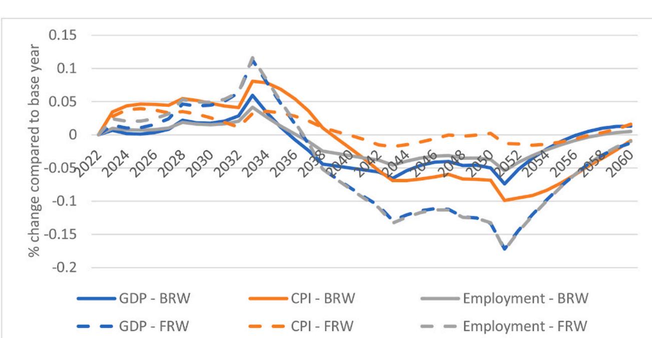

Fig. 8. Evolution of key macroeconomic variables under wage bargaining (BRW) and fixed wage (FRW) assumptions (stage 2 heat pump manufacturing and installation case, loans repayment method).

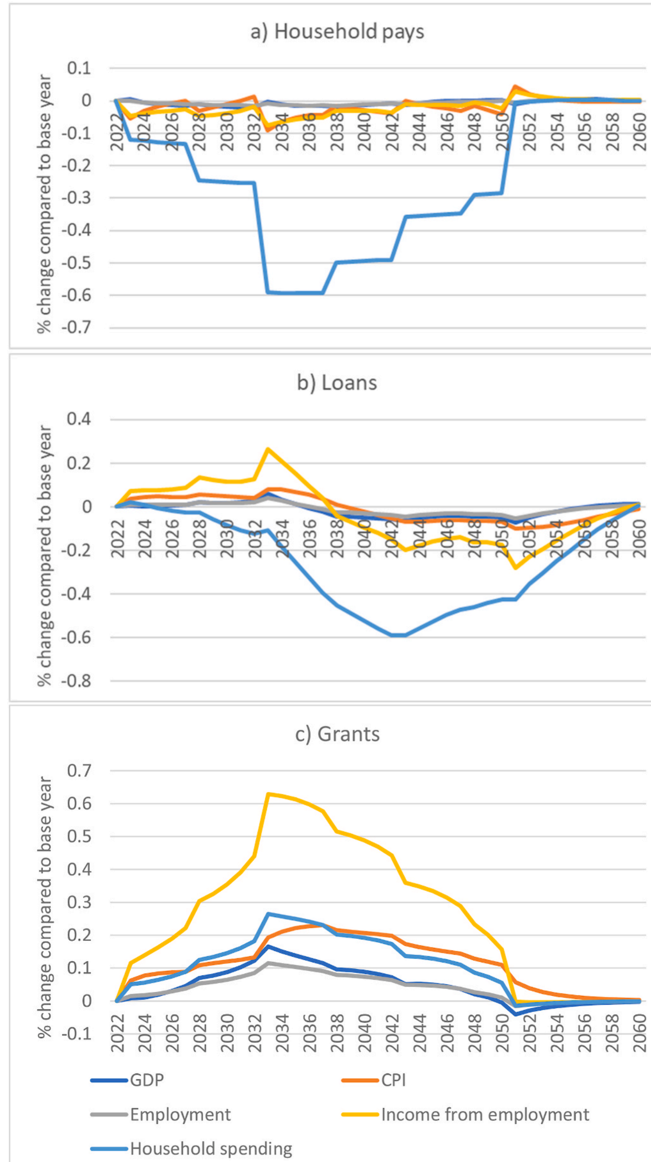

Fig. 9. Evolution of key macroeconomic variables under different heat pump repayment methods (stage 2 heat pump manufacturing and installation case).

The differences between the three financing mechanisms highlight the importance of household consumption in determining the economy-wide outcomes of the heat pump rollout, particularly in the timeframes when the rollout itself has concluded. The additional implication is that the impacts will be mostly concentrated in sectors where households tend to spend their income. Hence, the financing mechanisms can drive some, temporary, changes in the composition of the UK GDP, while also driving varying regional impacts, depending on the prevalence of certain sectors in the different regions of the UK.

Looking at the regional distribution of job creation and displacement for the different repayment methods (Fig. 10), we see similar trends as previously explored for stage 3 (see section 3.2.2), where there are new manufacturing and construction jobs across regions. Especially in the Midlands and northern areas. However, job displacement is also apparent, especially in certain regions that rely more on a service-based economy. Here, London is hit harder when households have to cover the cost of heat pumps (Fig. 10a and b), as the restrictions on household disposable income usually leads to less spending on hospitality, services, etc. These are some of the key sector in London economy, and hence job losses.

3.3. Discussion of results

To enable the low carbon heat transition, significant activity needs to take place. We have found that the network upgrade and heat pumps manufacturing and installation activity can be the (exogenous) trigger of economic gains. However, these gains are time limited. Moreover, any long-term economy-wide gains are linked to increased household consumption of good and services, driven by energy bill reductions as households use heat pumps to heat their properties. The magnitude of the gains in disposable income depends on the price difference between electricity and gas. The higher the price differential (i.e. how much more expensive is electricity relative to gas) the greater the erosion of the potential energy bills savings and consequently the smaller the potential economy-wide gains.

Our results also show that there will be large pockets of construction job creation (for network expansion and heat pump installation) in areas where large residential centres are located. A key policy challenge here is the skills and labour requirements and implications across different regions. Where the requirements exceed the availability of the regional labour force, this could drive a) job and economic activity relocation/displacement, and b) increase the cost of labour.

The job relocation and displacement linked to the activities of network upgrades and heat pump installation, bring up questions regarding skills implications and job distribution across regions. Could jobs lost in other sectors transition to construction? How different/similar are the skills of construction workers to develop different energy transition activities? What type of retraining is required? How mobile is the skilled workforce? Are they able/willing to reallocate to other regions? All these are important policy considerations that need attention, to ensure that transition to low carbon heat, and other energy transitions, are successful.

Taking for example the labour requirements for Scotland for heat pump installation activity. Our results suggest that around 1300 Construction and 1500 manufacturing jobs required in Scotland (see Fig. 5b). Does the Scottish economy have the necessary skilled and overall labour to meet these requirements? What would be the local community impacts? What type of training and support needs to be put in place to enable this? Is it likely that Scotland, and other regions with similar challenges, will have to source their missing labour from the excess labour in southern areas and if so what are the implications for the communities where these workers currently reside?

The demand for skilled labour is also likely to increase labour costs, putting pressure on wages. Increasing labour costs negatively affect employment in many labour-intensive industries (e.g. finance, consultancies, hospitality etc.); therefore, certain regions are lagging in terms of net job creation. This was the case, for example, in London for the activities linked to network upgrades and heat pump installation (see Fig. 6).

On the other hand, the higher energy efficiency of heat pumps could drive positive economic outcomes and long-term job creation. More heat pumps installed and used (under the right energy pricing conditions) could drive greater household income gains, and more household consumption across the economy and jobs created, as shown in our results for Fig. 3c d.e and Fig. 6c d.e. Here we expect that London and the Southeast outperform all the other regions, due to the economic composition and current levels of employment. So, the potential job gains in these regions driven by using heat pumps could help offset losses linked to the network expansion and heat pump installation activities. However, these may bring implications for the UK government levelling-up agenda (UK Government, 2022), if most jobs are created in areas with already higher employment opportunities, there is a risk that the disparity between regions is aggravated.

Looking at changes on income from employment as an indicator of quality of job improvements. Our results show that most new employment opportunities are located in sectors paying less than the median wage (primarily construction) with some uncertain potential employment opportunities in high wage manufacturing sector (based on where heat pump and ancillary equipment is manufactured). However, if the cost of the heat pump rollout and use does not restrict disposable income

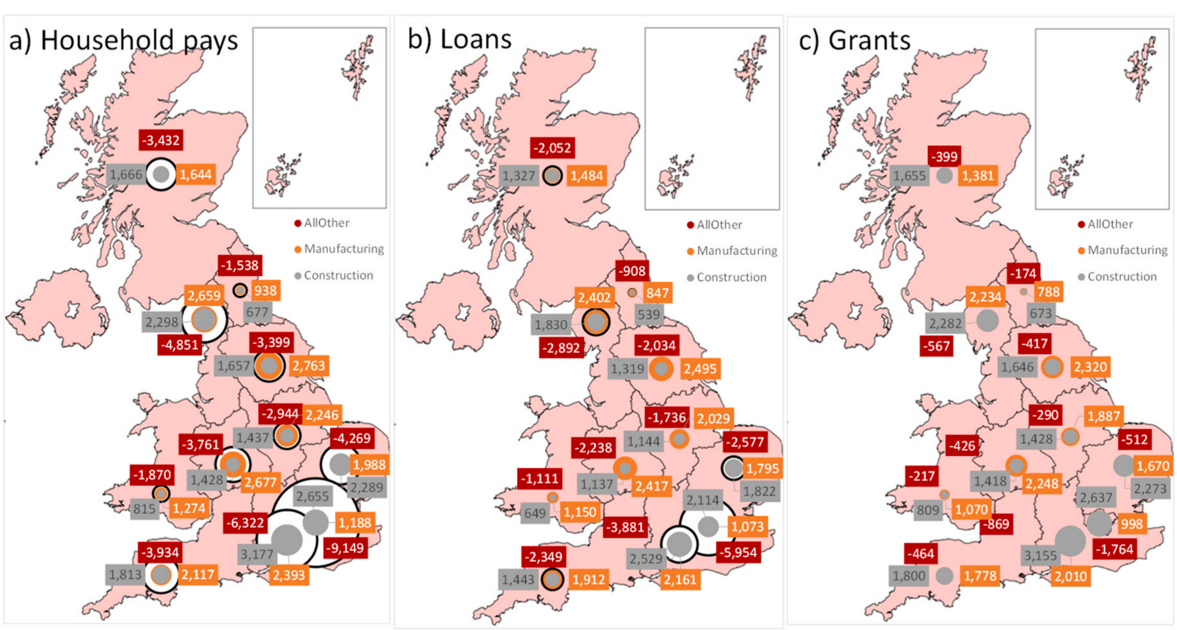

Fig. 10. Regional employment changes (FTE) at year 2033 (peak activity year) relative to baseline – stage 2 case, different repayment methods.

(e.g. under 1:1 price scenario), then the broader economic outcomes leads to a more than proportional increase of income from employment, indicating an improvement of the quality of jobs. However, if households' disposable income is reduced (e.g. under the 4.8:1 price scenario), this affects sectors offering higher wages than construction.

4. Conclusion and policy implications

Heating buildings is the source of nearly a quarter of UK emissions, and to meet the UK Government's Net Zero targets, virtually all heat generation in buildings needs to be decarbonised. To achieve this, significant changes to the energy system—including the upgrade of the energy networks—will be needed alongside the potential manufacturing and installation of new heating systems in residential properties. Here, a sufficiently large and skilled workforce will be a key enabler for these changes to happen, not only for the transition to low carbon heat, but for other net zero activities.

This paper examines the economic outcomes and regional employment implications of the projected heat pump roll out in the UK. Our results show that there will be large pockets of construction job creation (for network expansion and heat pump installation) in areas where large residential centres are located. However, these activities will drive job relocation and displacement, which brings up questions regarding skills implications and job distribution across regions. A key challenge here is whether local economies have the necessary skilled and overall labour to meet these requirements. Where requirements exceed availability, people may have to relocate. Additionally, there are questions on the difference or similarity of skills to develop different energy transition activities, on the type of retraining required to help the workforce transition, and on the availability and mobility of the skilled workforce. All these are important policy gaps that need attention, to ensure that the transition to low carbon heat, and other energy transitions, are successful.

The demand for skilled labour is also likely to increase labour costs, putting pressure on wages. We found that increasing labour costs negatively affect employment in many labour-intensive industries (e.g., finance, consultancies, hospitality etc.); therefore, certain regions are lagging in terms of net job creation. This was the case, for example, in London for the activities linked to network upgrades and heat pump installation. This brings another important policy implication, ensuring that there is a sufficient skill development pipeline, both nationally and regionally, supporting new entrants to the workforce and those transitioning from other sectors, ensuring the successful delivery of projects while managing wage pressures across the economy.

Our results also show that the higher energy efficiency of heat pumps could drive positive economic outcomes and long-term job creation. Under the right energy pricing conditions (where the relative price difference between electricity and gas is a big controlling factor) more heat pumps installed and used could drive greater household income gains, and more household consumption across the economy and jobs created. So, the potential job gains in these regions driven by using heat pumps could help offset losses linked to the network expansion and heat pump installation activities. However, these may bring implications for the UK government levelling-up agenda, if most jobs are created in areas with already higher employment opportunities, there is a risk that the disparity between regions is aggravated.

Addressing these policy gaps is crucial to ensure a balanced and equitable transition to low carbon heat. Policymakers need to consider the regional distribution of job creation vs availability and assess the potential for job displacement. National and regional strategies to support retraining and mobility of the workforce, while also addressing barriers on equality, diversity and inclusion (EDI), will be essential to mitigate negative impacts on certain regions and sectors.

Many of these challenges have been recognised in other developed nations (e.g. the USA, and the European Union) and across other net zero sectors (e.g. industrial decarbonisation, renewables and energy networks, etc). Therefore, these key findings and policy recommendations should be applicable to other sectors and global contexts.

4.1. Study limitations and future work

This study and the analysis provided is intended to provide insight on the jobs and skills requirements to enable the transition to low carbon heat in the UK. We believe this study is a required and important step in helping to assess the scale of the challenges and potential benefits. However, there are a number of considerations and limitations in our analysis, as described below, and we have also identified areas to further develop and refine this work.

The regional mapping is based on ONS breakdown on employment data by sectors and regions, which follows a coarse geographical spread (13 UK regions). We believe that this geographical data provides useful insight in the regional distribution of impacts on jobs and skills from the electrification of residential heat, but we recognise that some of these regions could be large in geographical terms (e.g. Scotland), and finer geographical detail would be preferable.

We take the assumption that current regional jobs and economic distribution may be a good reflection on 1) the future regional distribution of economic activity and linked jobs, and 2) where heat pump installation, and the related network upgrades, are more likely to take place. We recognise the uncertainty of the future regional economic composition and where heat pumps are more likely to be installed and used, which will drive economic activity and jobs. However, we have taken this approach as regional employment numbers tend to correlate with population size, which can also be used as a proxy for household numbers and heat pump installations. Crucially, we see this work as a key step in identifying locations and sectors of interest, where significant labour challenges may arise.

As future work, we intend to further refine our mapping of employment changes using other available data, including but not limited to population size and density, and building stock data in terms of accommodation type (flat, house, detached/semi-detached) and EPC rating. This information would allow us to assess where heat pump installations are more likely to take place and where other competing technologies may be more prevalent. For example, high density areas with majority of flats may be more cost effective to implement a district heating system, whereas less dense and/or houses may favour heat pump installation.

In addition to this, we will seek to utilise finer geographical data, to produce a more detailed mapping of jobs and skills implications. Potentially at local authority level or finer, depending on available data. Also, we will seek to expand our analysis, via extensive stakeholder engagement (e.g. practitioners, industry bodies, training providers, consumer groups and policy makers), to gain better understanding of the specific skills required across the different activities, and how this is reflected into our mapping.

CRediT authorship contribution statement

Christian F. Calvillo: Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Antonios Katris:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Long Zhou:** Writing – review & editing, Validation, Methodology, Investigation, Formal analysis, Data curation. **Karen Turner:** Writing – review & editing, Validation, Supervision, Resources, Project administration, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Christian Calvillo reports financial support was provided by UK Energy Research Centre.

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Appendix A. CGE model sectoral aggregation

Table 1
Sectoral aggregation in CGE model and link to SIC2007 codes (ONS, 2022).

Sector Number	Sector Name	SIC code
S1	Agriculture, Forestry and Fishing	01–03
S2	Coal and Lignite	05
S3	Crude Oil and Gas	06–07
S4	Other Mining and Mining Support	08–09
S5	Food, Drinks and Tobacco	10–12
S6	Textile, Leather and Wood	13–16
S7	Paper and Printing	17–18
S8	Coke and Refined Petroleum Products	19
S9	Chemicals	20
S10	Pharmaceuticals	21
S11	Rubber and Plastic	22
S12	Cement, Lime and Glass	23
S13	Iron, Steel and Metal	24&25.4
S14	Manufacture of Fabricated Metal Products, excluding weapons & ammunition	25.1–3 & 25.5–9
S15	Electrical Manufacturing	26–28
S16	Manufacture of Motor Vehicles, Trailers and Semi-Trailers	29
S17	Transport Equipment and Other Manufacturing (incl. Repair)	30–33
S18	Electricity	35.1
S19	Gas Distribution	35.2–3
S20	Natural Water Treatment and Supply Services	36
S21	Waste Management and Remediation	37–39
S22	Construction - Buildings	41–43
S23	Wholesale and Retail Trade	45–47
S24	Land Transport	49
S25	Other Transport	50–51
S26	Transport Support	52–53
S27	Accommodation and Food Service Activities	55–56
S28	Communication	58–63
S29	Financial and Insurance Services	64–66
S30	Architectural Services	71
S31	Services	68-70 & 72-82
S32	Public Administration, Education and Defence	84–85
S33	Health and Social work	86–88
S34	Recreational and Other Private Services	86–94

Appendix B. – Sectoral aggregation for regional data mapping

Table 2
Sectoral aggregation and mapping between CGE model and ONS workforce data sectors.

CGE sectors	Sector aggregation on workforce data (ONS, 2022a)	SIC 2007 section
S1	Agriculture, forestry & fishing	A
S2 - S4	Mining & quarrying	B
S5 - S17	Manufacturing	C
S18,S19	Electricity, gas, steam & air conditioning supply	D
S20,S21	Water supply, sewerage, waste & remediation activities	E
S22	Construction	F
S23	Wholesale & retail trade; repair of motor vehicles and motorcycles	G
S24,S25,S26	Transport & storage	H
S27	Accommodation & food service activities	I
S28	Information & communication	J
S29	Financial & insurance activities	K
S30,S31	Real estate activities	L

(*continued on next page*)

Table 2 (*continued*)

CGE sectors	Sector aggregation on workforce data (ONS, 2022a)	SIC 2007 section
	Professional scientific & technical activities	M
	Administrative & support service activities	N
S32	Public admin & defence; compulsory social security[1]	O
	Education	P
S33	Human health & social work activities	Q
S34	Arts, entertainment & recreation	R
	Other service activities	S
	People employed by households, etc[2]	T

Appendix C. – Summary of scenario parameters

Table 3
Summary of scenario parameters and assumptions considered.

Scenario	Parameter	Value
Stage 1	Expected heat pump adoption by 2050	65%
	Expected network upgrade costs until 2050	£21.1billion
	Distribution of spending: UK Construction sector	1/3
	Distribution of spending: imported	2/3
Stage 2	Assumed heat pumps to be installed	10.2 million
	Assumed total heat pump costs	£122.3billion
	Average cost per heat pump installation	£11,960 (incl. VAT)
	of which installation costs (installations assumed to be carried out by the UK Construction sector)	£3680
	% of heat pumps to be sourced in the UK	25%
	Assumed loan repayment timeline	10 years (interest free)
Stage 3	Assumed heat pump coefficient of performance (COP)	2.52
	Assumed residential energy demand reduction	40%

Data availability

Data will be made available on request.

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