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Socio-macroeconomic impacts of meeting new build and retrofit UK building energy targets to 2030: a MARCO-UK modelling study

Jaime Nieto, Paul Brockway, John Barrett

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Sustainability Research Institute (SRI), School of Earth and Environment,

The University of Leeds, Leeds, LS2 9JT, United Kingdom

Tel: +44 (0)113 3436461

Fax: +44 (0)113 3436716

Email: SRI-papers@see.leeds.ac.uk

Web-site: https://sri-working-papers.leeds.ac.uk/

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Abstract

Reducing energy consumption in UK buildings is a key part of measures required to meet Net Zero carbon emissions goals by 2050. The UK's Buildings Mission aims at reducing new build energy use to 50% of current levels by 2030. At the same time, the UK's 2017 Clean Growth Strategy contains targets relating to retrofit of existing buildings: for homes to be upgraded to band C by 2030, and non-domestic properties to improve energy productivity by 20% by 2030.

Researchers at the University of Leeds undertook a macroeconometric study to estimate the broader socio-macroeconomic impacts of energy reduction targets to new and existing domestic and non-domestic buildings in the UK. The modelling analysis used the University of Leeds' MARCO-UK econometric model. Key results across different scenarios include quantification of actual total energy reduction and finding wider benefits including higher GDP, jobs, wages and disposable income.

Key words: Macroeconomic modelling; energy systems; thermodynamic efficiency; energy targets; building energy reduction.

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About the Authors

Jaime Nieto is a Research Fellow in Energy Economics at the Sustainability Research Institute at the University of Leeds, UK. He works at CREDS on energy-economy modelling. Previous to this, he worked on the European project MEDEAS, where he provided support in economy modelling and the integration of Input-Output analysis into the system dynamics framework. His research interests are focused on ecological economics and low-carbon economy transitions.

Paul Brockway is a University Academic Fellow in Energy and Economics at the Sustainability Research Institute at the University of Leeds, UK. His research is focussed on studying macroeconomic energy economy interactions, through primarily the lens of

exergy analysis. Exergy is considered as 'available energy', and enables the study of the energy conversion chain from primary to final to useful stages - where it is lost in exchange for energy services.

John Barrett is Professor in Energy and Climate Policy at the Sustainability Research Institute at the University of Leeds, UK. John heads the CREDS Theme on “Industry, Materials and Products”. His research interests include energy demand, resource productivity, energy and economy modelling, carbon accounting and exploring the transition to a low carbon future.

Executive summary

This report assesses the social and macroeconomic effects of energy reduction scenarios for new and existing domestic and non-domestic buildings in the UK, consistent with the UK's Clean Growth Strategy and Grand Challenge Buildings Mission ambitions. Their objective is to reduce energy use in the UK via energy efficiency improvements in domestic and non-domestic buildings, which form one of the largest energy using parts of the UK economy. We have translated the energy reduction goals into the following Building Energy Targets (BET):

- Buildings Mission: By 2030, new build homes and non-domestic buildings use 50% of average building energy use in 2018
- Clean Growth Strategy: By 2030, 95% of all Band D-G properties are retrofitted to Band C Energy performance certificate (EPC) standard, and a 20% energy reduction is achieved (versus baseline) for non-domestic buildings.

The MARCO-UK model has been used to carry out a scenarios analysis. MARCO-UK is a simulation, macroeconometric model, with 57 equations and 84 variables with historical data from 1971 to 2016. A key novelty of this model is the role of energy efficiency in the socioeconomic system. MARCO-UK is mainly a demand-side model, with counter-balancing feedback loops to ensure model stability when exogenous policies are introduced.

The main scenarios defined for this analysis are the following:

1. New build energy targets: ~3 million (Domestic) and ~120,000 (Non-Domestic) new build properties built to tighter energy targets by 2030.
2. New build: The same as 1, but meeting the tighter energy targets more quickly, by 2026.
3. Retrofit to move to Band C the existing EPC Band D-G domestic buildings by 2030.
4. Retrofit to reduce 20% the energy use of the existing non-domestic buildings by 2030.
5. Scenarios 2, 3 and 4 together. (SCEN 5a includes a higher skills upgrade)

As a result of applying these scenarios to MARCO-UK, the total final energy use is reduced in absolute terms (vs 2019) in SCEN 4 and SCEN 5. In addition, the total final energy use is reduced by 2030 compared to the Baseline by -4% to -19% depending on the scenarios. Regarding the macroeconomic effects, the average GDP to total investment ratio reaches 1.40, meaning a 40% return on investment. The building retrofit policies are more significant in socioeconomic terms than the new build policies, due mainly to their larger scale. Nevertheless, a combination of all policies (SCEN 5) has the largest impacts in both socioeconomic and energy terms. Moreover, in SCEN 3 and SCEN 5, the additional capital investment is significant enough to yield larger socioeconomic effects than the other scenarios (2% and 3.2% higher annual capital investment). Finally, accounting for the labour skills upgrade (SCEN 5a) has an overall positive effect at a macroeconomic level.

MARCO-UK is a macroeconometric model well suited for capturing demand-side stimulus to the economy, as well as the role of energy efficiency in the economy. MARCO-UK is also able to include energy efficiency rebound effects. In addition, the model shows the benefits of combining capital investment with public expenditures for national accounting reasons and to avoid an excessive capital stock accumulation

1 Introduction

1.1 Context: Energy reduction in UK buildings as part of Net Zero goals

Figure 1 shows in a pie chart the share of total emissions of all UK sectors in 2017. As can be seen, the buildings-related sectors, i.e. Business, Public and Residential, amount to around 50% of total GHG emissions. This share has remained more or less constant since 1971. From the same point of view, according to DUKES[1], the energy use of the Domestic and Services sectors represented 44% of total final energy use. Moreover, the sector that was once the largest energy consumer of the economy (40% of the total), industry, represents just 16% today. Therefore, the UK building stock is associated with the largest share of GHG emissions and final energy use in the UK's economy, and energy reductions as part of a strategy to meet New Zero carbon policy [1] are much needed.

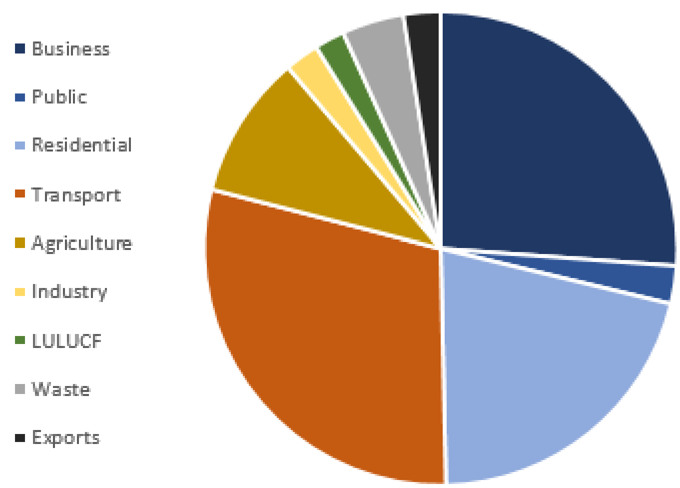

Figure 1. GHG Emissions by sectors in the UK (2017). Source: own elaboration based on DBEIS data.

1.2 The policy response: UK Building Energy Targets

In 2017, the UK Government published the Industrial Strategy White Paper [2]. The Industrial Strategy stated four Grand Challenges: 1. Artificial Intelligence and data; 2. Ageing society; 3. Clean growth; 4. Future of mobility. In May 2018[2], the UK Government published details of the Clean Growth Grand Challenge Buildings Mission, with the aim "*to at least halve the energy use of new buildings by 2030"*[3].

The Government also published its Clean Growth Strategy in 2017 [3] which outlined a retrofit ambition to upgrade existing homes to Energy Performance Certificate (EPC)

[1] https://www.gov.uk/government/statistics/energy-chapter-1-digest-of-united-kingdom-energy-statistics-dukes

[2] https://www.edie.net/news/11/Theresa-May-unveils-plan-to-halve-building-energy-use-by-2030/

[3] https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/missions#buildings

Band C by 2035, where “cost effective, affordable and practical”, with an earlier goal for rented homes of 2030. This is in addition to the Government’s statutory target to improve the homes of fuel poor households, “as far as reasonably practicable”, to EPC Band C by 2030. For commercial buildings, the Clean Growth strategy sets an ambition of a 20% increase in business energy productivity by 2030.

1.3 This report

This report assesses the main socioeconomic impacts of the planned new build and retrofit building energy use reduction targets and the investment required to realise these. The results have been obtained by defining different scenarios in MARCO-UK, a macroeconometric energy-environment-economy model developed at the University of Leeds. For our analysis, we have translated the energy reduction goals into the following Building Energy Targets (BET):

- Buildings Mission:
  - By 2030, new build homes use 50% of average domestic building energy use in 2018
  - By 2030, new build non domestic buildings use 50% of average non domestic building energy use.
- Clean Growth Strategy:
  - By 2030, 95% of all Band D-G properties are retrofitted to Band C Energy performance certificate (EPC) standard.
  - By 2030, 20% energy reduction versus baseline for non-domestic buildings.

In addition to the planned energy reduction, investments are also included which are aimed at delivering the increase in UK buildings’ energy efficiency.

With this purpose, this report is structured as follows:

- Section 2 describes the MARCO-UK model and outlines the differences from other modelling approaches.
- Section 3 outlines the definition of the MARCO-UK model scenarios from the Building Energy Targets including energy use reduction and capital investments.
- Section 4 outlines the macro-economic impacts of the Building Energy Targets. The main modelling outputs are described here.
- Section 5 collects the main concluding remarks of the analysis.

2 MARCO-UK model

2.1 Overview of the modelling approach

2.1.1 Post-Keynesian background

MARCO-UK is a macro-econometric (ME) model based (as is common) on post-Keynesian economic theory, where agent behaviour is not based on optimisation but is instead determined from econometric equations based on historical data. Like other macroeconometric models, MARCO-UK is a demand-driven model, following the tradition of other similar post-Keynesian-related models, such as E3ME [4], developed by Cambridge Econometrics, and the macroeconomic model used by the Office for Budget Responsibility (OBR) [5].

The economy is conceptualised as a non-equilibrium system in the sense that markets are often not efficient and that prices and quantities do not adjust to optimal, market-clearing levels. Instead, post-Keynesians consider that prices are set by firms using some form of mark-up pricing, although it is acknowledged that the interplay of supply and demand can impact prices in some markets. It is assumed that in most circumstances not all resources are optimally used and that spare capacity exists in the economy, which allows economic growth to be demand led both in the short and long run. In the short run, production adjusts to increased demand through the increase in the utilisation of capacity, while in the long run the total capacity of the economy adjusts to demand through increased levels of investment.

As a result, economic production is not constrained by supply-side factors in the MARCO-UK model. Post-Keynesian theory recognises that supply-side factors, especially insufficient labour supply, can constrain production in unusual circumstances. Such constraints are not explicitly built into the MARCO-UK model, but we take them into account by rejecting any scenarios in which employment outstrips the available labour force.

Our model contains over 70 socio-technical-economic variables, including thermodynamic-based energy variables (primary energy, final energy, and useful exergy; thermodynamic efficiency at primary-to-final and final-to-useful conversion stages). A fuller description of the model is contained in Sakai *et al*.[6]. These energy variables are fully integrated into the model structure, as opposed to conventional soft-linking energy and economy module. An inherent weakness of the ME models lie in their econometric construction: this means they generally forecast historical trends to continue. Thus our model can struggle to study how a structural change in the economy would respond in the future. However, as the model is designed to allow each variable to be exogenous, this allows the development of scenarios that break historical trends if sound evidence can be provided.

2.1.2 MARCO-UK: A thermodynamically-consistent energy-economy model

MARCO-UK is an energy-economy-wide UK model which includes thermodynamic efficiency conversion and its linkages to the macro-economy. We also expand on existing macroeconometric models by including the useful stage of energy consumption (as useful exergy), as shown below in Figure 2. The inclusion of thermodynamic efficiency and useful exergy allows us to investigate their roles in economic growth. Useful exergy is the energy used at the last energy conversion stage before exchange for energy services. The final-to-useful stage is rarely studied at an economy-wide level, but as Figure 2 below illustrates, it is where most thermodynamic energy conversion losses occur. Such inclusion within modelling frameworks could thereby be important for improving the evidence base for energy efficiency policy and its effect of economic growth. The closest relative in this regard to the MARCO-UK model is the Department for Business, Energy and Industrial Strategy (BEIS) Energy Demand Model, which models and forecasts useful energy, but with much less socio-economic linkages than the MARCO-UK model.

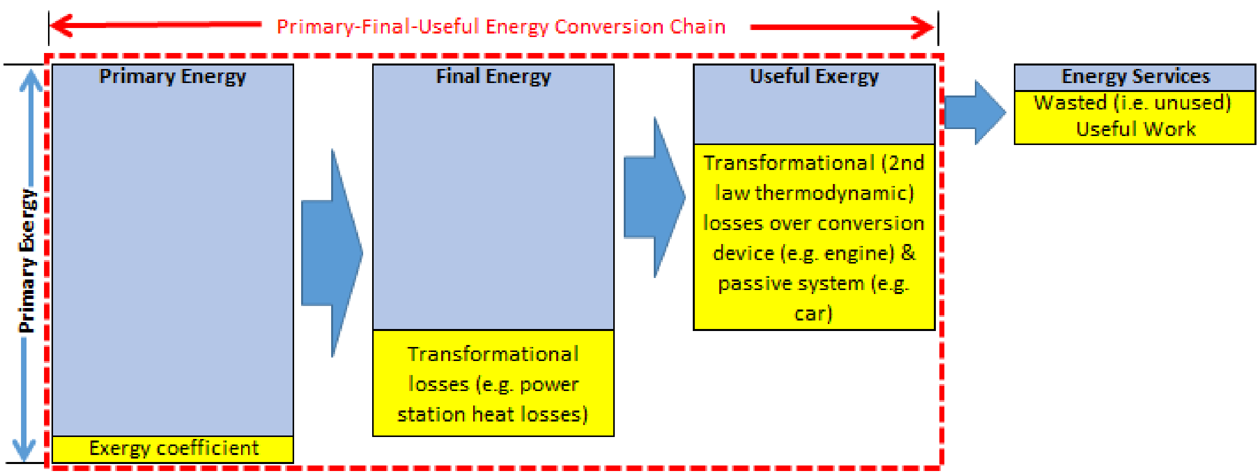

Figure 2: MARCO-UK includes energy at primary-final-useful energy stages (From Brockway et al. [7])

2.1.3 How does it compare to a general equilibrium model?

Archetypal CGE models are developed from well-specified, micro-economic theory in which behavioural relationships are derived from optimising agents and in which prices "clear" markets continuously so that resources are optimally employed [8]. However, these assumptions are often relaxed in the current generation of CGE models to allow for labour market imperfections and involuntary unemployment, which implies that "equilibria" are not necessarily "optimal" in any sense. CGEs have typically been regarded as reflecting an ultra-neoclassical view of the world in which demand may not matter much (if at all) and supply influences are expected to dominate in terms of affecting the aggregate real economy. Moreover, CGE's use of optimisation and aggregated production functions based on perfect substitutability of productive factors can model any combination of resources' use and total economic output.

CGE models rely strongly on theoretical assumptions with regard to the behavioural functions, and also assume that the economy as a whole is in equilibrium in the base year. On the one hand, these assumptions allow the construction of detailed models without large amounts of historical time-series data, as many parameters in the model can be derived from the calibration to a single base year (although it should be noted that some parameters in CGE models are also estimated econometrically). In addition, the stronger alignment with economic theory can provide CGEs with an advantage in terms of interpreting model results. On the other hand, CGE models have sometimes been subject to the "black box" criticism: the models are so complex that it is difficult to understand what is going on inside them.

In contrast to the largely neoclassical-based CGE models, macroeconometric models such as MARCO-UK have a more empirically-derived construction, using timeseries data. This feature enables counterfactual simulations to be run over the model's time frame, to isolate the effects caused by changes to any variable (e.g. thermodynamic efficiency) on the whole economy. In the case of MARCO-UK, the model timeframe is 1971-2050, which allows both the study of ex-post (1971-2016) and ex-ante (2016-2050) scenarios to investigate macroeconomic effects of past or future policies/changes to the economy. For this current analysis, we conduct an ex-ante analysis (2016-2030) of the Building Energy Targets to quantify the associated socio-macroeconomic impacts on the UK. Such isolation provides an advantage over other modelling approaches, like Computable General Equilibrium (CGE) models. As a consequence of MARCO-UK model's structure, it can be considered a simulation Integrated Assessment Model. Simulation models have flexibility to capture disequilibrium, propagation of disturbances and policy effects over the system analysed [9]. Thus, whilst from very different theoretical and empirical foundations, both CGE (optimisation) and ME (simulation) models are commonly applied to long-run equilibrium analysis, such as the macroeconomic impact study presented here.

2.2 Model Construction

2.2.1 Econometric model structure

Like other ME models, MARCO-UK contains two types of equations. The first type involves definitional relationships, also known as 'identities', which represent definitions of given variables and must hold true in all time periods. The second type of equations are known as 'behavioural' or 'stochastic', which contain parameters estimated econometrically. The present version of the model contains 57 equations: 30 are identities and 27 are stochastic. The main identities are given by the accounting definitions of gross domestic product (GDP). From the expenditure side, GDP is equal to the sum of private (C) and public (G) consumption, investment (I) and net exports (X-M). From the income side, GDP is defined by total national income (i.e. compensation of employees, profits received by firms, etc.) plus net taxes. These two identities must hold for each time period. Each of the components of GDP is estimated econometrically on an individual basis through a stochastic equation. The particular functional forms and choice of explanatory variables are empirically validated and tested using econometric techniques. Apart from GDP components, the model includes stochastic equations for other variables, such as capital, labour, prices, energy and others. Figure 3 shows a simplified schematic of the relationships between energy and economic variables found at the core of the model, although the graph does not include all the relationships between variables.

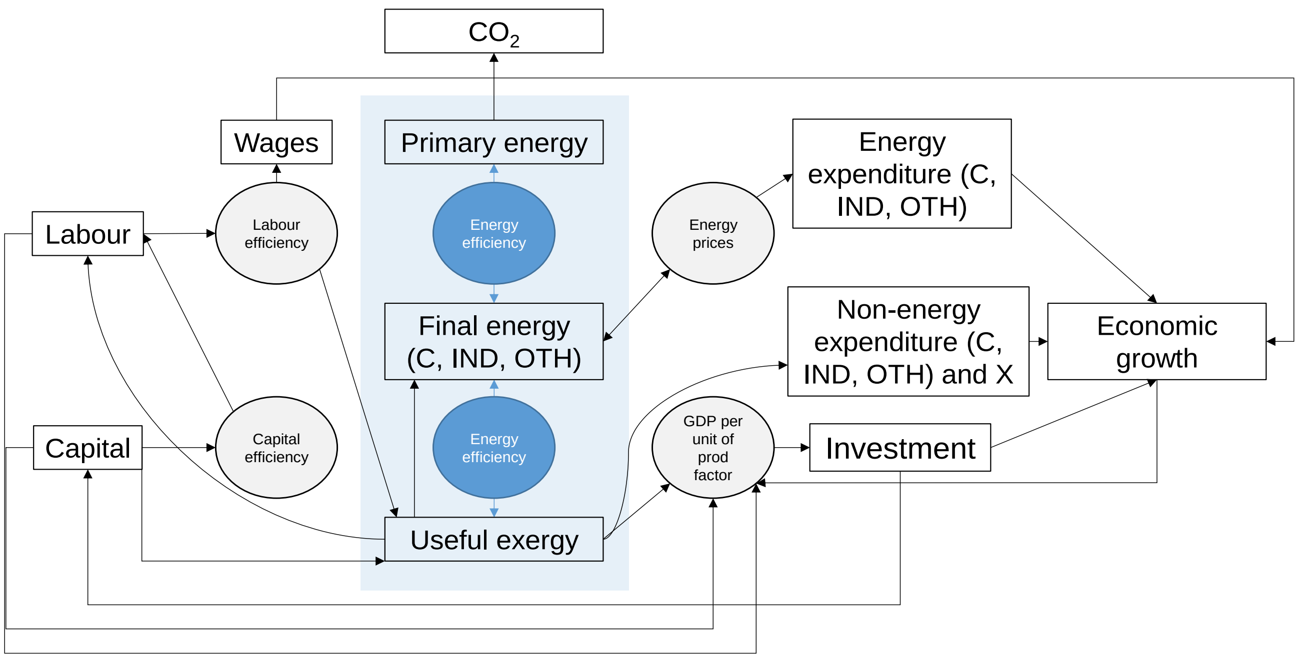

Figure 3: Schematic MARCO-UK model structure (From Sakai et al. 2018 [6])

2.2.2 Main causality loops in MARCO-UK

Figure 4 shows one of the main causality loops in MARCO-UK, which may be helpful to understand the overall results subsequently presented. In MARCO-UK, the energy-economy interaction plays a central role in determining the main macroeconomic relationships. As the energy reduction is exogenously forced in this analysis, the starting point would be the increase to capital investment. This would increase thermodynamic efficiency, increasing energy services. This, in turn, would entail incentives to production (by lowering the cost of goods for producers) and increases in non-energy consumption. Therefore, a rebound effect takes place in MARCO-UK, whereby economic output is partly driven higher by gains in thermodynamic (energy) efficiency.

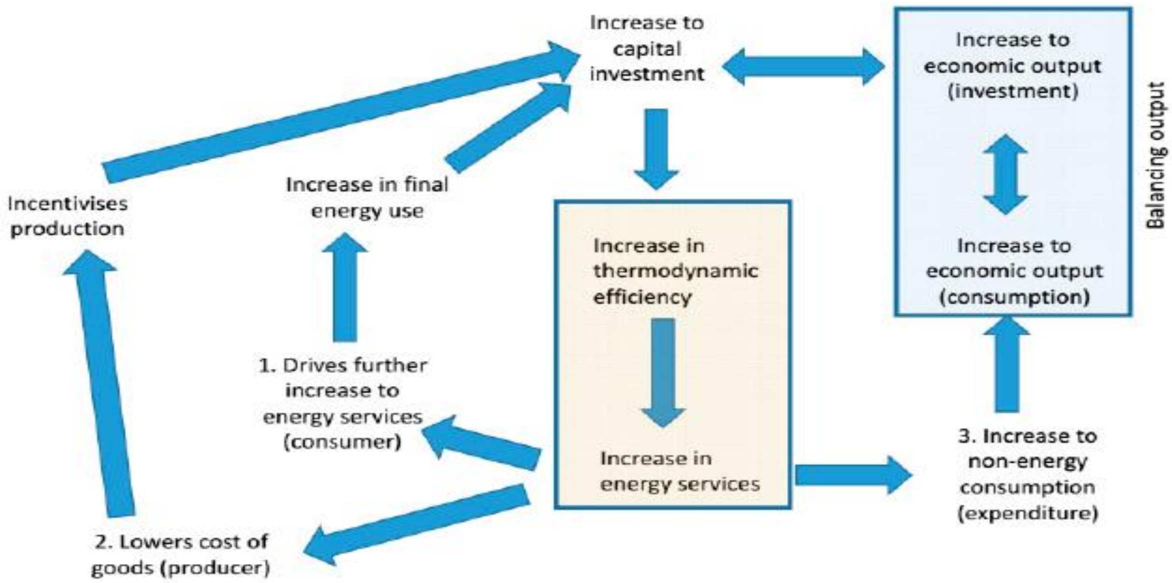

Figure 4. Schematic overview of the investment-thermodynamic efficiency feedback loop. (From Sakai et al. 2018 [6])

In order to understand other causality loops in MARCO-UK, we show in Figure 5 the effects caused by an increase in Government Expenditures (G) and Capital Investment (I), policies applied in this analysis. Figure 5 shows the causality relationships between key socioeconomic variables. The correct way to read Figure 5 is following the solid (direct causality) lines first and then the dashed (indirect causality) lines, to understand the indirect effects of the first causality loop.

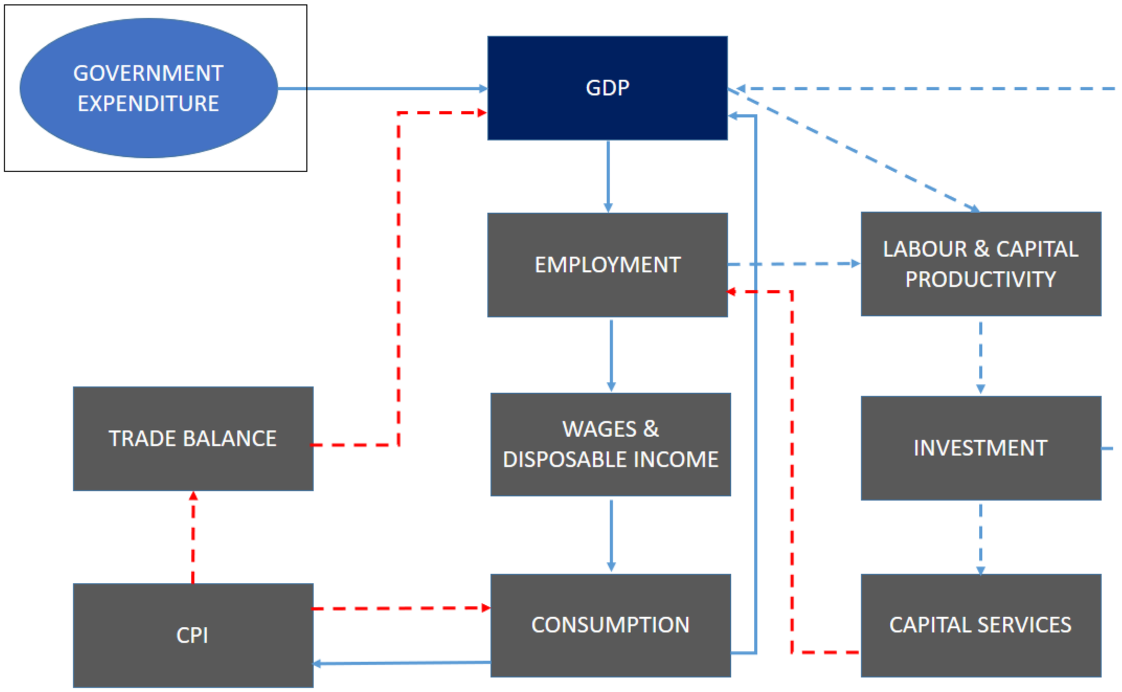

Figure 5. Schematic causality loop of a demand-side variation in MARCO-UK.

Key: Blue arrows indicate positive relationship (an increase leads to an increase, and the other way round)
Red arrows negative relationship (an increase leads to a decrease and vice versa).
Solid lines represent direct, or short-term, relationships
Dashed lines represent an indirect, or medium-term, effect

So, for instance, additional G would directly add to GDP, as an impulse to aggregate demand, leading to a higher level of employment. This, in turn, would increase wages and disposable income, resulting in an upsurge of private consumption. This would reinforce aggregate demand, increasing GDP but, at the same time, it may raise prices (CPI). So, in subsequent periods, the higher increase of GDP compared to the increase in the level of employment, would translate into an increment of labour and capital productivity which, in turn, would stimulate capital investment, which would result in more benefits in terms of GDP. However, simultaneously, by this process, the capital stock grows, leading to an increase in the capital services. This makes labour comparatively less attractive for employers, who would increasingly prefer capital instead, reducing employment and therefore lowering wages, consumption and, eventually, GDP. At the same time, the rise of prices reduced the exporting capacity of the economy, as well as the upsurge of private consumption increased imports. As a consequence, the trade balance lowers GDP. So, there are counterbalancing feedbacks that contain the initial effects of an increase in aggregate demand.

Moreover, the negative feedback loop observed from the investment side, would be higher if the aggregate demand stimulus comes directly from this option. This is because the negative effect does not come indirectly, but directly, so the multiplicative effect of G does not take place. It depends on the intensity of the capital investment increase how large this feedback loop is. It also has to do with the profitability-imperative that all capital relies on. So, if the capital stock increases at a rate that the economy is not able to cope with, a deceleration of the economic output growth appears.

All this can be illustrated via a sensitivity analysis for G and I, shown in Figure 8 - Figure 8, whereby a 10%, 20% and 30% increase over the Baseline was applied for both variables. In this way, each variable has been labelled considering three components: 'Variable code'_'Sensitivity variable'+ '%change vs Baseline'. For instance, 'Y_INV +10%' shows the GDP (Y) plot for a scenario where investment (INV) has exogenously been increased 10% over the Baseline. Or, 'L_G +30%' is the total employment (L) plot for a scenario where government expenditures (G) has been increased by 30% over Baseline.

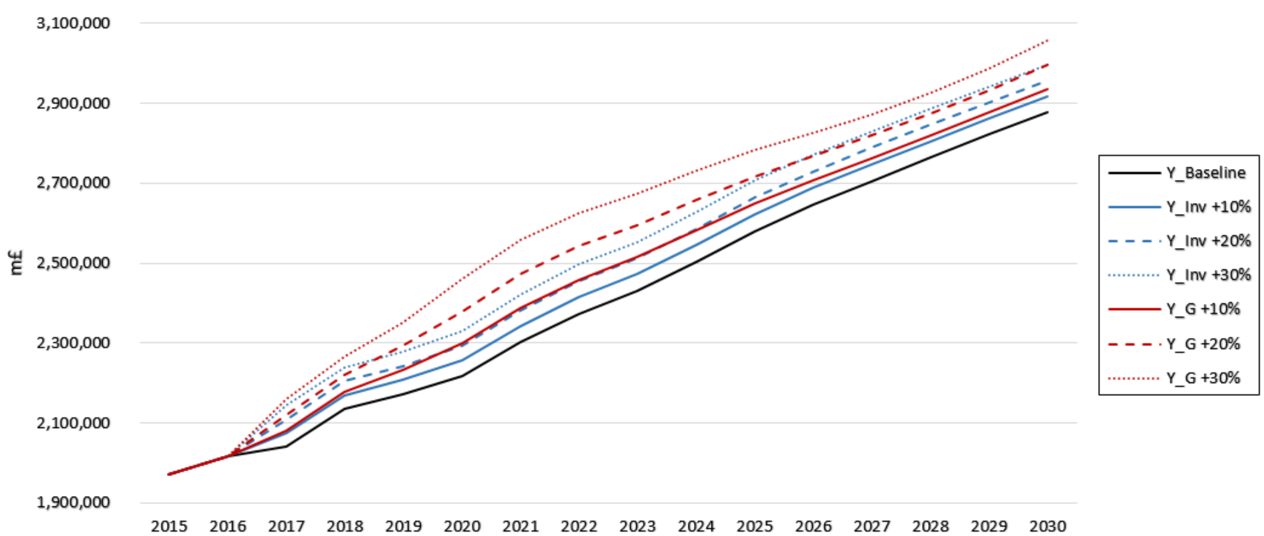

Figure 6. Sensitivity analysis for Investment and Government Expenditures: impacts on GDP (m£)

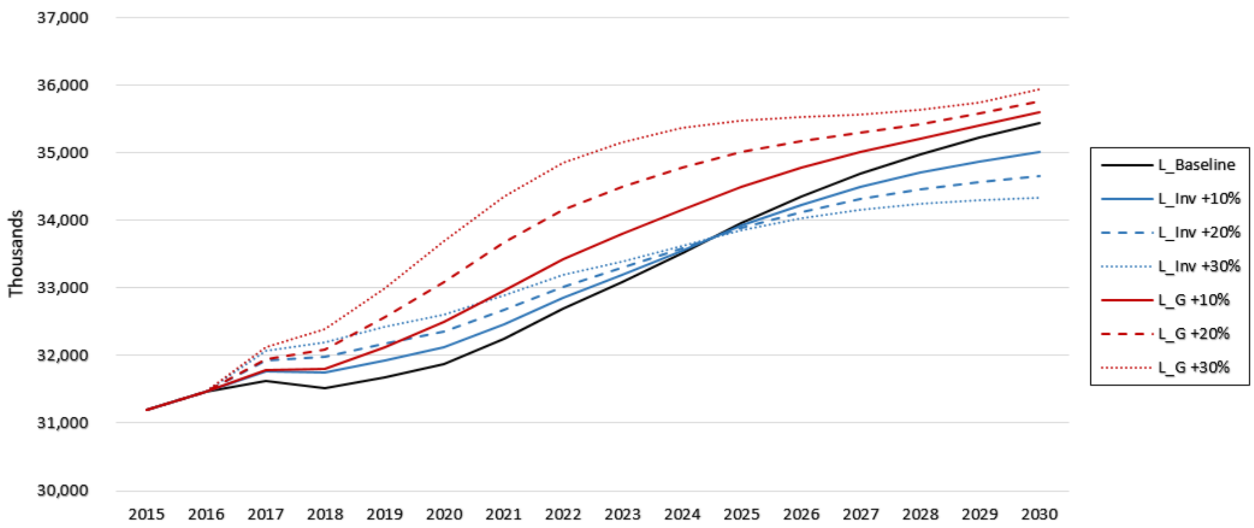

Figure 7. Sensitivity analysis for Investment and Government Expenditures: impacts on Employment (L) (thousands)

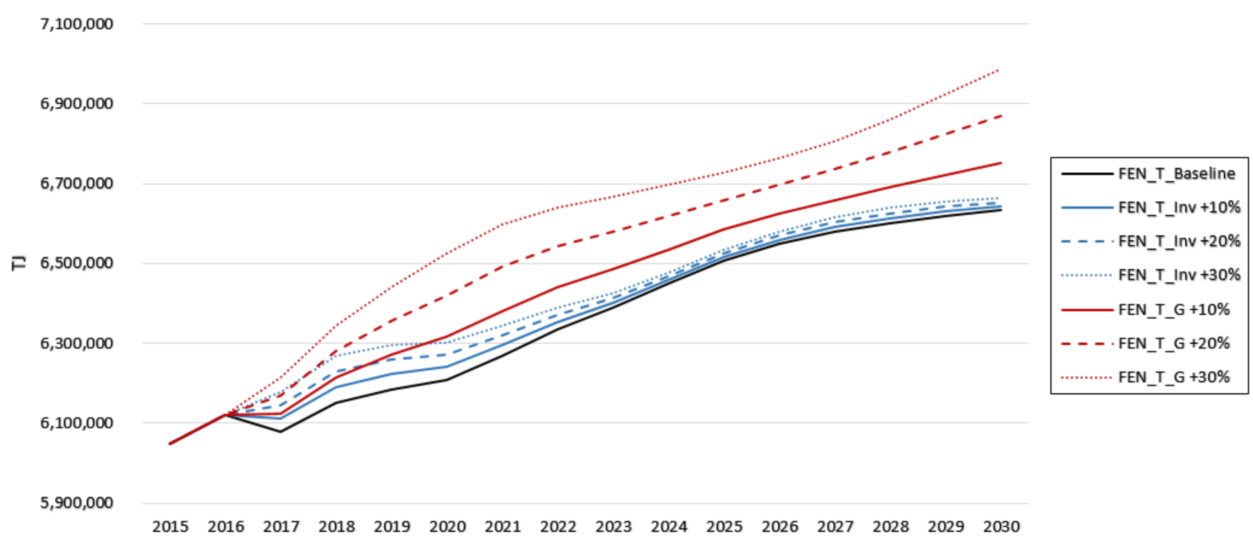

Figure 8. Sensitivity analysis for Investment and Government Expenditures: impacts on GDP (m£), Final energy use (FEN_T) (TJ)

The GDP plot shown in Figure 6 shows that the negative effects after a Government expenditures increase are lower compared to a capital investment policy, eventually leading to higher GDP prospects. This is even more obvious in terms of employment shown in Figure 7. Since the negative feedback loops are direct when increasing the capital stock above its normal (historical) rate, employment could even end up below the baseline estimations after the first positive shock. Finally, in terms of energy use shown in Figure 8, Investment shows a better performance, provided it has capacity to increase energy efficiency. Thus, despite its initial effect increasing energy use, it finishes around the same point as Baseline. In contrast, Government expenditures make energy use increase, even though their indirect effect on investment slows the increase at the end of the period.

Nevertheless, as long as G is considered a constant proportion of GDP(slightly increased by the exogenous scenarios), it therefore becomes partially endogenous, and capital investment would also increase G and in turn GDP. So, the combination of both strategies is appropriate for the purpose of the BET scenarios.

For additional information on the model construction and sensitivity analyses, see Supplementary Materials in Sakai *et al*. [10].

3 Scenarios definition

3.1 General considerations

As mentioned before, MARCO-UK is well positioned to assess the implications of different policies and their propagation across the economy. Because MARCO-UK is an econometric model, a 'no-policies' simulation will return the *Business as usual* or *Baseline (BL)* results, representing a projection of past trends. The BL scenario is taken as the reference to which the policies' scenarios are compared in order to estimate their impacts. Once a policy target is set as an input to the model, the outcomes will define other possible paths. The more policy targets are included in the model, the more possible trajectories that can be tracked. Policy targets are normally introduced as scenarios. Scenarios can either include just one policy target – useful for exploring the isolated effect of a policy, or multiple policies to explore how they operate simultaneously. A step-by-step procedure has been conducted in order to check the strengths and weaknesses of each scenario, building up on the previous one and eventually simulating an All-policies scenario.

The scenarios are described as follows:

1. **Building Mission I – linear development. New build energy reductions (Households and Non-Households).**
Linear reduction vs baseline in 2030.
50% of energy use reduction in new build (vs average building energy use) by 2030.

1a As above but includes capital investment (from Currie & Brown report [11]) with investment following energy reduction profile

2. **Building Mission II – steeper development. New build energy reductions (Households and Non-Households).**
Steeper reduction vs baseline in 2030.
50% of energy reduction in new build (vs average building energy use) by 2026. Then, carry on with same 50% new build energy reduction 2026-2030.

2a As above but includes capital investment (from Currie & Brown report [11]), with investment following energy reduction profile.

3. **Retrofit existing homes. Energy use reduction in existing homes**
£65Bn investment to move 95% of Band D-G (EPC) homes to Band C by 2030. Linear addition to Baseline capital investment projection. 40% of this figure has been considered public expenditures, following Washan *et al*. [12].

4. **Retrofit non-domestic buildings.**
£23Bn (total investment) and -20% energy savings (in last year, 2030). 40% of the total investment is considered public expenditures, following Washan *et al.* [12].

5. **Retrofit existing homes + Building Mission II. Combination of Scenarios 2a, 3 and 4.**

5a As above, but includes labour skills upgrade for the additional jobs created in SCEN5.

Table 1 summarises the set of actions undertaken in each scenario:

Table 1. Actions overview of the Building Energy Targets. Scenarios outline for Domestic (D) and Non-Domestic (N)

Action	SCEN1		SCEN1a		SCEN2		SCEN2a		SCEN3		SCEN4		SCEN5		SCEN5a	
	D	N	D	N	D	N	D	N	D	N	D	N	D	N	D	N
Reduced energy (NB)	■	■	■	■												
Steeper energy reduction (NB)					■	■	■	■					■	■	■	■
Retrofitting existing stock									■			■	■	■	■	■
Capital Investment			■	■			■	■	■			■	■	■	■	■
Government Expenditure									■			■	■	■	■	■
Improving labour skills																■

Next, Table 2 shows the % energy reduction that has been applied to the model as inputs for each scenario. (More information on the values is given in Section 3.2).

Table 2. Inputs to scenarios in MARCO-UK modelling of the Building Energy Targets. New Build (NB), Retrofit (R), Domestic (D) and Non-Domestic (N).

	Energy Use (% reduction over sectoral baseline							Capital Investment (m £)	Government Expenditures (m £)	Total (m £)
	DOMESTIC			NON-DOMESTIC			Total			
	NB	R	Total D	NB	R	Total N				
SCEN1	-2.3		-2.3	-1.5		-1.5	-1.5			
SCEN1a	-2.3		-2.3	-1.5		-1.5	-1.5	7,058		7,058
SCEN2	-3.4		-3.4	-2.3		-2.3	-2.3			
SCEN2a	-3.4		-3.4	-2.3		-2.3	-2.3	12,871		12,871
SCEN3		-15.2	-15.2				-4.4	39,000	26,000	65,000
SCEN4					-20		-11.0	13,800	9,200	23,000
SCEN5	-3.4	-15.2	-18.6	-2.3	-20	-22.8	-18.0	65,671	35,200	100,871
SCEN5a	-3.4	-15.2	-18.6	-2.3	-20	-22.8	-18.0	65,671	35,200	100,871

Other general assumptions

Some other initial assumptions have been considered before running the analysis. These must be regarded to better understand and interpret the results, as well as to draw consistent conclusions. These assumptions are listed below:

1. Energy prices (Domestic and Non-Domestic): These have been controlled not to exceed the Baseline values. An efficiency-driven reduction in energy use may lead to an initial decrease in energy prices. This would trigger in turn a rebound effect, increasing energy demand and pushing prices back up. This feedback effect is intensified by the fact that we are exogenously imposing an energy demand decline. Hence, the economy is demanding more energy but it is being reduced, driving an escalation of energy prices. In order to avoid a misrepresentation of reality, prices follow the Baseline values in all scenarios.
2. Capital investment vs government expenditures split: The Blue Book of the UK's National Accounts[4] (p. 47) states that there are examples of Gross Fixed Capital Formation (i.e. capital investment): "*spending on machinery and equipment, transport equipment, software, artistic originals, new dwellings and major improvements to dwellings*". Therefore, all new build investment has been considered capital investment. But the retrofit has been divided between capital investment (major improvements to dwellings) and government expenditures (minor improvements). For the sake of simplicity, a 60-40 split between capital investment and government expenditures has been applied following Washan *et al.* [12]. In the following overview (Figure 9) the accounting components of GDP (expenditure side) are broken down. The components of the national accounts that the BETs are financed with are boxed in red:

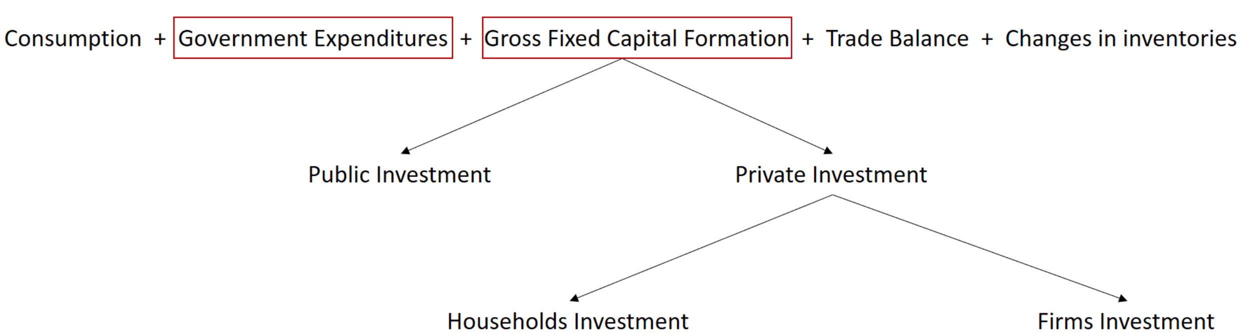

Figure 9. Expenditure-based GDP components, broken down by institutional sectors.

[4] https://www.ons.gov.uk/economy/grossdomesticproductgdp/compendium/unitedkingdomnationalaccountsthebluebook/2018

3. Government Expenditures: this has been set as a 19% proportion of GDP for all scenarios including Baseline, based on recent historical data. Government expenditures on the BET was added on top of that value. Despite that, the overall Government Expenditure is not changed substantially.
4. Employment in SCEN1 and SCEN2: this was calculated by assuming the same labour productivity as in Baseline. We have considered that new dwellings and new offices would not really have a significant impact on labour productivity, which would otherwise be accounted for by the model (since the capital stock is increased by the investments).

3.2 Main inputs to MARCO-UK

3.2.1. Energy savings

According to the scenarios' outline described in Section 3.1, the energy use of both the Domestic and Non-Domestic sector has been exogenously reduced, and the relevant energy percentage reductions have been applied to the non-Baseline scenarios. All the values given in this section, especially in Table 3 to Table 5, have been collected from the UK government's Housing surveys, energy trends and regional dwelling stock surveys (see References for links).

Domestic

Table 3 shows the percentage reduction in energy use over Baseline in all scenarios for the Domestic sector. In order to estimate this for Domestic New Build (SCEN1 and SCEN2), the proportion of the new dwellings for each year (2019-2030) in the total dwelling stock was first calculated. Then, for SCEN1, we applied that in 2030 the new dwellings that year had 50% energy reduction, with a linear interpolation between 2018 and 2030. For SCEN2, the target is reached in 2026, with linear interpolation between 2018-2026, and constant 50% energy reduction for each year of new dwellings 2026-2030. The dwelling stock data has been collected from the different national statistics agencies (see references).

Table 3: Energy savings in the Domestic sector. New Build (NB) and Retrofit (R)

DOMESTIC					SCEN1	SCEN2	SCEN3	SCEN5
Units	(thousands)			(%)				
	NB	Total stock	NB Stock	NB Stock / Total	(NB) Reduction / Baseline	(NB) Reduction / Baseline	(R) Reduction / Baseline	(NB+R) Reduction / Baseline
2017	-	28,753	-	-	-	-	-	-
2018	253.52	29,007	-	-	-	-	-	-
2019	253.52	29,260	254	0.9	- 0.0%	- 0.0%	- 1.3	- 1.3%
2020	253.52	29,514	507	1.7	- 0.1%	- 0.1%	- 2.5	- 2.6%
2021	251.4	29,765	758	2.5	- 0.2%	- 0.2%	- 3.8	- 4.0%
2022	246.18	30,011	1,005	3.3	- 0.3%	- 0.4%	- 5.1	- 5.5%
2023	244.08	30,255	1,249	4.1	- 0.4%	- 0.6%	- 6.3	- 7.0%
2024	244.9	30,500	1,494	4.9	- 0.6%	- 0.9%	- 7.6	- 8.5%
2025	241.33	30,741	1,735	5.6	- 0.8%	- 1.2%	- 8.9	- 10.1%
2026	245.16	30,987	1,980	6.4	- 1.1%	- 1.6%	- 10.1	- 11.7%
2027	242.21	31,229	2,222	7.1	- 1.3%	- 2.0%	- 11.4	- 13.4%
2028	239.27	31,468	2,462	7.8	- 1.6%	- 2.4%	- 12.6	- 15.1%
2029	234.28	31,702	2,696	8.5	- 1.9%	- 2.9%	- 13.9	- 16.8%
2030	231.89	31,934	2,928	9.2	- 2.3%	- 3.4%	- 15.2	- 18.6%

Regarding the Domestic Retrofit (SCEN3), estimations were done on the total stock of dwellings broken down according to their Energy Performance Bands (EPC), as shown in Table 4. The objective is moving all D to G dwellings to band C. As a conservative approach, it was considered that 5% of all these dwellings were not able to be moved to band C. The energy used (TJ) by dwelling was estimated for all bands and then the energy intensity of band C dwellings (0.05 TJ/Dwelling) was applied to dwellings from D to G (excluding 5% of them). Consequently, overall energy used would be reduced by 15.2% in 2030 (Tables 3 and 4). This percentage reduction in 2030 is achieved gradually during the 2019-2030 period, following a linear path. Data on dwellings per EPC band was collected from the UK Government energy trends[5].

[5] https://www.gov.uk/government/publications/energy-trends-december-2017-special-feature-article-domestic-energy-consumption-by-energy-efficiency-and-environmental-impact-2015

Table 4. Domestic Retrofit pre-calculations to estimate the total final energy reduction in SCEN3.

Energy Performance Band	AB	C	D	E	F	G	Total
Dwellings ('000s)	374	8281	14520	4140	1093	374	**28,753**
Total TJ	35,659	420,336	883,412	302,582	90,075	23,476	**1,787,324**
TJ/Dw	0.095	0.050	0.060	0.074	0.080	0.067	**0.071***
TJ/Dw if all Band C	0.095	0.050	0.050	0.050	0.050	0.050	**0.058***
TJ if all Band C **	35,390	417,355	733,438	216,615	66,281	20,035	**1,489,117**
% Energy saving	-	-	- 17.0 %	- 28.4 %	- 26.4 %	- 14.7 %	**- 15.2 %**

*Average.

** 5% of all houses could not be moved to Band C. Proportion higher in G and decreasing towards D.

Finally, for Domestic energy use, SCEN5 is the combination of SCEN2 and SCEN3. As a result of this addition, the reduction over Baseline would reach 22.1% in 2030. The profile of the Households energy use is shown in Figure 10. Every year these reductions are deducted from the Baseline, so the gap between the households' total energy use in Baseline and the scenarios increases until it reaches the reduction target. Only SCEN3 and SCEN5 would imply absolute reductions in energy use. SCEN4 is not shown since no actions on the Domestic sector are implemented.

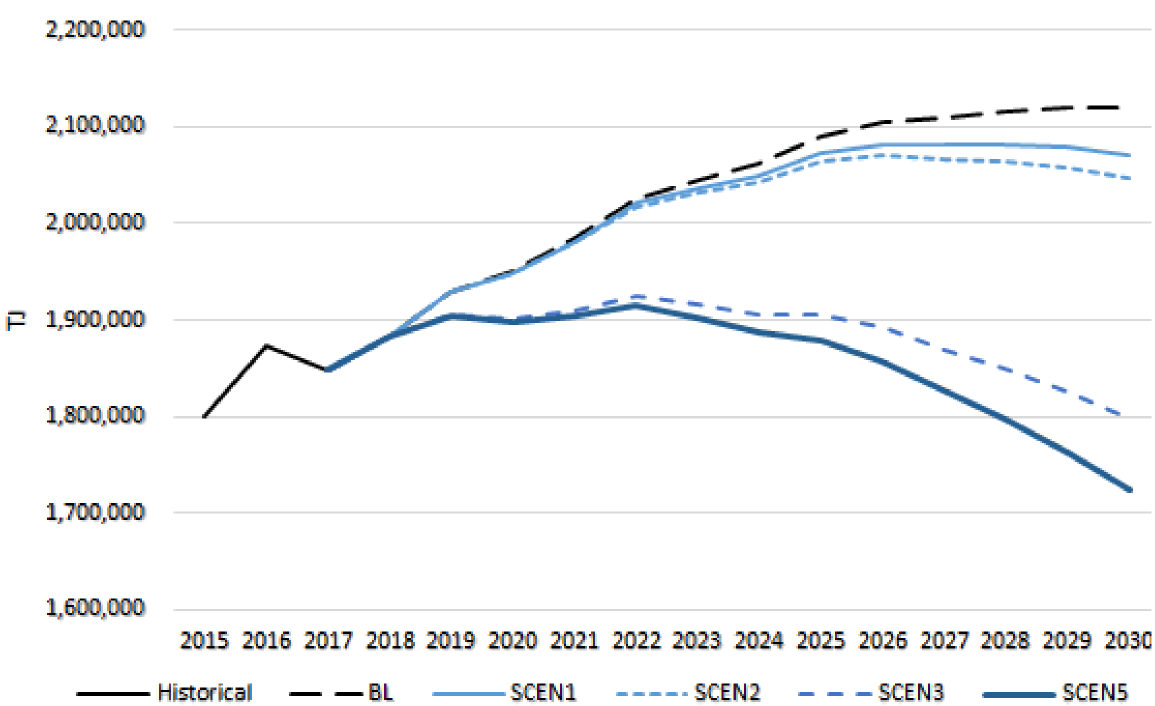

Figure 10. Households' (Domestic) final energy use in different scenarios

Non-Domestic

Energy savings in Non-Domestic are also divided into New Build and Retrofit. Table 5 summarises the percentage reduction over Baseline in all scenarios for Non-Domestic. The same approach as for Domestic has been followed for SCEN1 and SCEN2. SCEN3 only proposes actions on Domestic, so no actions are undertaken on Non-Domestic. On the other hand, for SCEN4 a linear reduction has been applied in energy use until it reaches a 20% decrease in 2030 over Baseline, considering a retrofit of the existing stock of Non-Domestic buildings. Finally, SCEN5 is a combination of SCEN2 and SCEN4.

Table 5. Energy savings for Non-Domestic. New Build (NB) and Retrofit (R)

NON-DOMESTIC					SCEN1	SCEN2	SCEN4	SCEN5
Units	(thousands)			(%)				
	NB	Total stock	NB stock	% NB Stock / Total	(NB) Reduction / Baseline	(NB) Reduction / Baseline	(R) Reduction / Baseline	(NB+R) Reduction / Baseline
2017	-	1,830	-	-	-	-	-	-
2018	5.6	1,836	-	-	-	-	-	-
2019	6.1	1,842	6	0.3	- 0.0	- 0.0	-1.7	-1.7
2020	6.6	1,848	13	0.7	- 0.0	- 0.0	-3.3	-3.4
2021	7.2	1,855	20	1.1	- 0.1	- 0.1	-5.0	-5.1
2022	7.8	1,863	28	1.5	- 0.1	- 0.2	-6.7	-6.9
2023	8.4	1,872	36	1.9	- 0.2	- 0.3	-8.3	-8.6
2024	9.2	1,881	45	2.4	- 0.3	- 0.5	-10.0	-10.5
2025	9.9	1,891	55	2.9	- 0.4	- 0.6	-11.7	-12.3
2026	10.8	1,902	66	3.5	- 0.6	- 0.9	-13.3	-14.2
2027	11.7	1,913	78	4.1	- 0.8	- 1.1	-15.0	-16.1
2028	12.7	1,926	90	4.7	- 1.0	- 1.5	-16.7	-18.1
2029	13.8	1,940	104	5.4	- 1.2	- 1.8	-18.3	-20.2
2030	14.9	1,955	119	6.1	- 1.5	- 2.3	-20.0	-22.3

As a result of these figures, the Non-Domestic energy use gradually declines compared to Baseline, as depicted in Figure 11. Only the retrofit scenarios (SCEN4 and SCEN5) would to deliver energy use reductions in absolute terms.

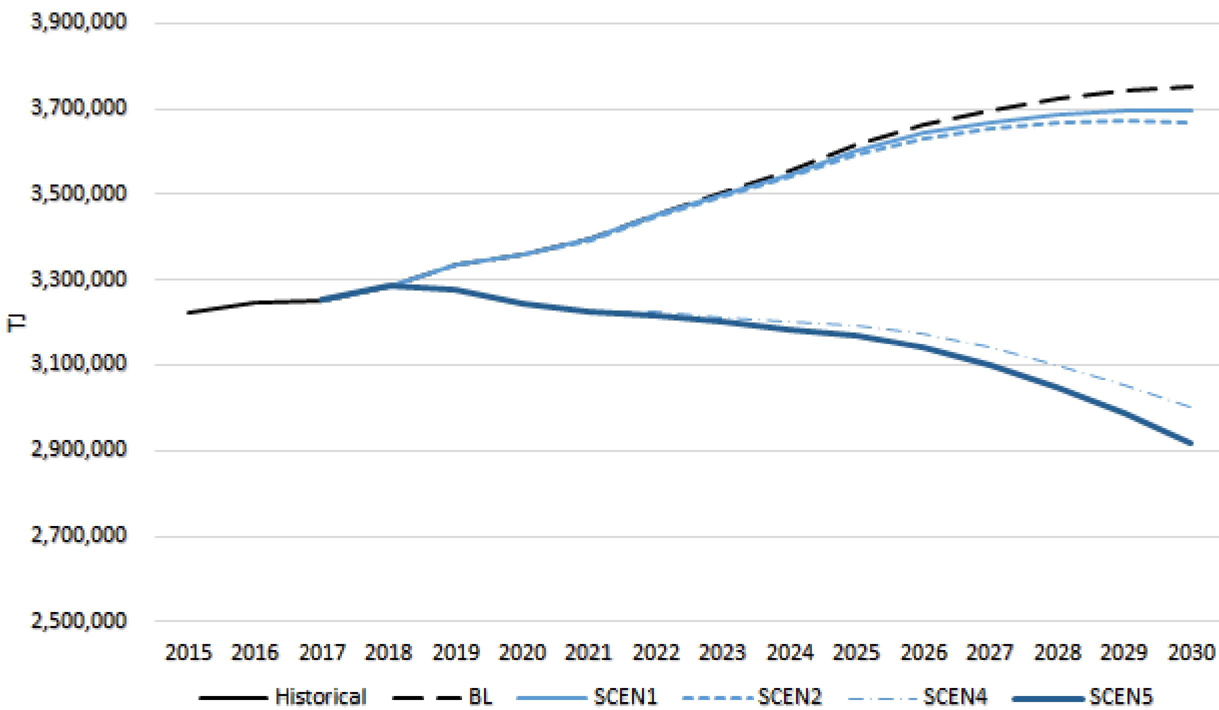

Figure 11. Non-Domestic final energy use in all scenarios.

3.2.2. Investment

Investment is aimed at funding the different BET actions and it has been split between Gross Fixed Capital Formation (i.e. capital investment) and government expenditures. All government expenditures are allocated to the building retrofit strategy, i.e. only present in SCEN3, SCEN4 and SCEN5. All the investment flows are additional to the total investment that would have been made under the Baseline scenario. Therefore, additional investment has been added to the BL estimates.

Calculations have been made based on the final Currie and Brown report to the CCC on "The costs and benefits of tighter standards for new buildings" [11]. So, different investment parameters have been applied to either the area of the buildings or the type of dwellings, taken from the Housing Survey headline report (section 2)[6]. The investment (both capital investment and government expenditures) for all the scenarios are presented in Table 6:

[6] https://www.gov.uk/government/statistics/english-housing-survey-2016-to-2017-headline-report

Table 6. Additional total investment (capex + government expenditures) in all scenarios.

	Capital investment (Capex), million £					Government expenditure, million £		
Year	SCEN1a	SCEN2a	SCEN3	SCEN4	SCEN5	SCEN3	SCEN4	SCEN5
2019	184	326	3,250	1,150	4,726	2,167	767	2,933
2020	259	488	3,250	1,150	4,888	2,167	767	2,933
2021	333	647	3,250	1,150	5,047	2,167	767	2,933
2022	404	797	3,250	1,150	5,197	2,167	767	2,933
2023	476	952	3,250	1,150	5,352	2,167	767	2,933
2024	553	1,116	3,250	1,150	5,516	2,167	767	2,933
2025	623	1,263	3,250	1,150	5,663	2,167	767	2,933
2026	707	1,442	3,250	1,150	5,842	2,167	767	2,933
2027	778	1,450	3,250	1,150	5,850	2,167	767	2,933
2028	848	1,459	3,250	1,150	5,859	2,167	767	2,933
2029	912	1,459	3,250	1,150	5,859	2,167	767	2,933
2030	982	1,473	3,250	1,150	5,873	2,167	767	2,933
Total	**7,058**	**12,871**	**39,000**	**13,800**	**65,671**	**26,000**	**9,200**	**35,200**

SCEN1a consists of investments for Domestic and Non-Domestic new build. SCEN3 is 60-40 capital investment and government expenditures for Domestic retrofit with the same split as in SCEN4 for retrofitting the Non-Domestic buildings. Finally, SCEN5 is the summation of SCEN2a, SCEN3 and SCEN4. As a result of this distribution, Figure 12 shows the total investment – differentiating between capital and government expenditures – for each scenario.

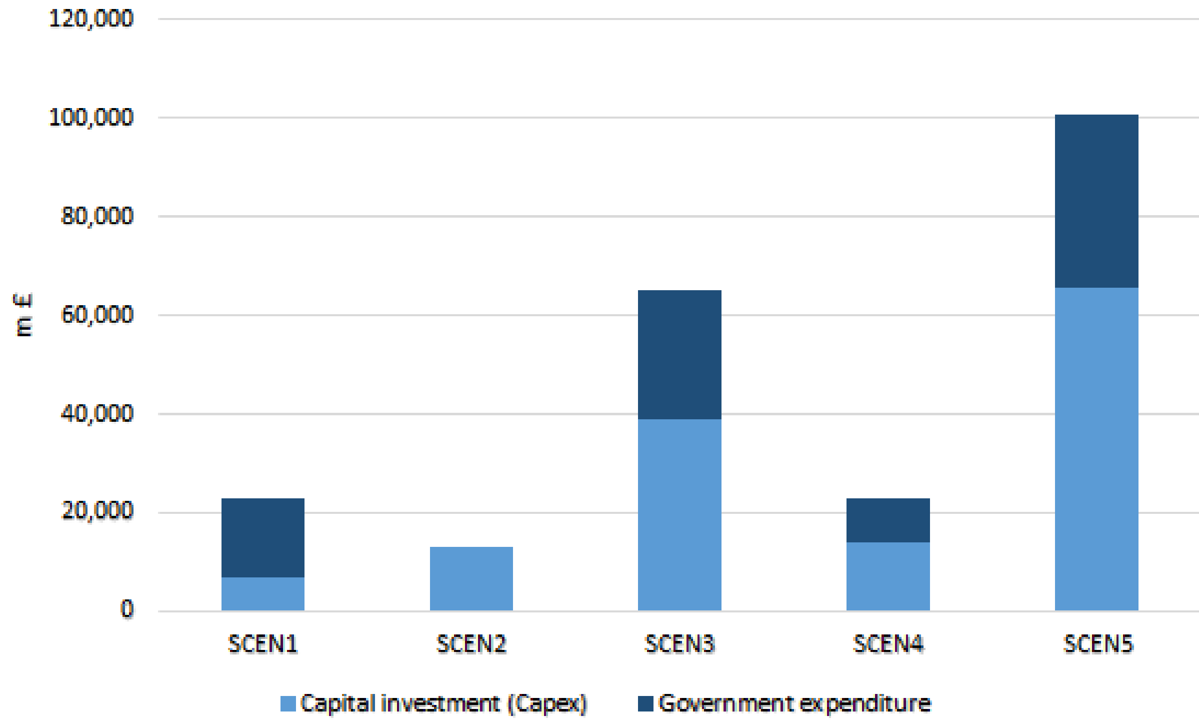

Figure 12. Total investment (capex + government expenditures) by scenarios (2019-2030).

3.2.3. Labour skills

An additional SCEN5a has been simulated in order to test the effects of an upgrade of labour skills due to the additional jobs created by the BET. It has been added to SCEN5, since it is the scenario which creates highest number of additional jobs (see Section 4.3), so the effects of the skills upgrading is more appreciable. It must be taken into consideration that the additional annual jobs created in SCEN5a on top of the Baseline scenario reach a maximum of 200,000 - representing around 0.6% of total labour force. So, even though it has been considered that all the additional jobs are of higher skills, its macroeconomics effects cannot be much greater than that proportion. Nevertheless, the marginal effect of the upgrading can be assessed by comparing the results with the other scenarios. MARCO-UK accounts for this effect with a quality-adjusted variable for labour skills. It is calculated by multiplying labour (L) by two indices: the average annual hours worked by persons engaged (L_HRS_INDEX) and the human capital index, based on years of schooling and returns to education (L_HC_INDEX), both exogenously projected.

$$HL_t = L_t * L\_HRS\_INDEX_t * L\_HC\_INDEX_t$$

Hence, in order to apply the policy, this index has been increased by the proportion of new workers over the total labour force. This guarantees a proportional increase in the labour-adjusted index for skills, considering that all the additional jobs are high skilled.

4 Socio-macroeconomic impacts of the Buildings Energy Targets

A set of energy and macroeconomic variables have been selected to represent the implementation of the BET in the MARCO-UK model. Different formats of the results are displayed in this section, having been selected to best suit the different nature of the variables. For instance, it makes sense to represent the total additional GDP accumulated during the decade (compared to Baseline) since it is a flow (income) feeding a stock (wealth). In contrast, additional jobs cannot be accumulated. Rather, employment in year ‘t’ can be 100 units higher than Baseline, but if it is 150 units higher in ‘t+1’, that does not mean that 250 jobs have been created. What this means is that the economy’s total level of employment varies dynamically during the simulation period. For this reason, the average annual difference against Baseline is reported. In addition, ratios have been used to represent variables such as the unemployment rate or the comparison between the potential BET benefits and its costs.

We present the results in the following sub-sections:

- Section 4.1: Energy
    - Total Final Energy use (FEN_T).
    - Thermodynamic efficiency (EXEFF_FU2).
- Section 4.2: GDP and productivity
    - GDP
    - Energy and labour productivity
- Section 4.3: Jobs and unemployment
    - Additional Jobs.
    - Unemployment Rate (UR).
- Section 4.4: Wages and disposable income
    - Total wages (W).
    - Wages per hour (W_HOUR).
    - Disposable Income (Y_D).
- Section 4.5:Modelling limitations and assumptions

In appendix A we present Summary detailed tables of the 17 key variables.

4.1 Energy

Although final energy use in domestic and non-domestic buildings has been reduced through the BET, the industry sector could be affected by the policies applied (e.g. as the economy grows). So, in Figure 13 total final energy use is shown.

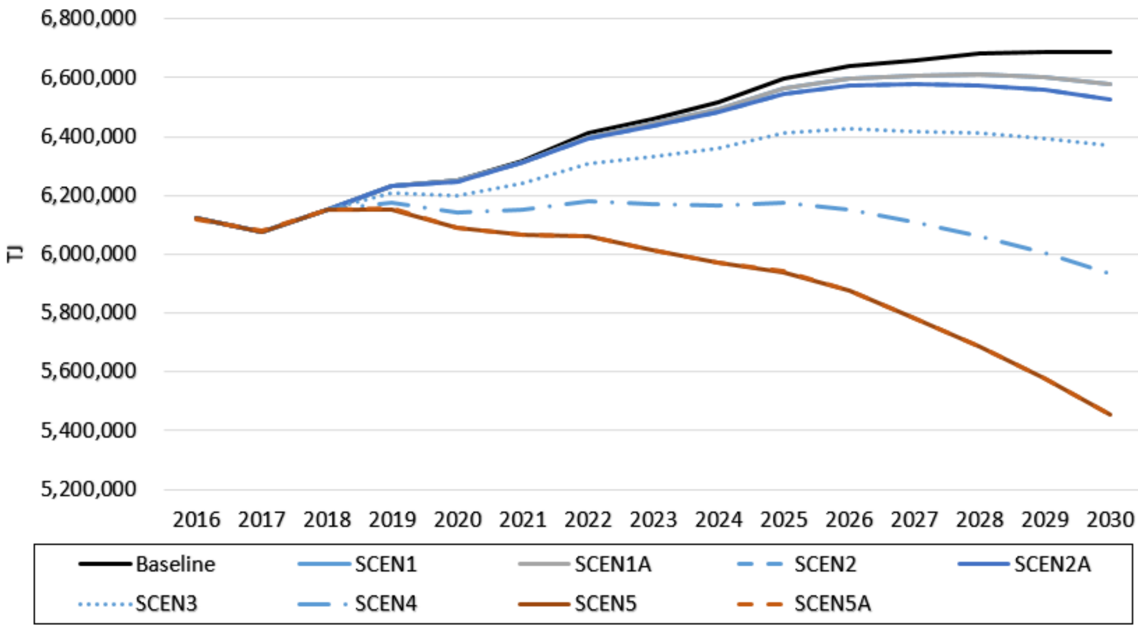

Figure 13: Total Final energy use (fen_t) under baseline and BET scenarios

Despite the industry energy use slightly increasing compared to Baseline, overall final energy use continues its decreasing path, meaning total final energy use is reduced in all scenarios against Baseline. Nevertheless, only SCEN4 and SCEN5 are able to attain an absolute reduction of energy use. So, if this outcome is desired, retrofitting non-domestic buildings would be the minimum required. But, if a significant absolute reduction is to be achieved, then SCEN5 (the combination of SCEN2a, SCEN3 and SCEN4) would be the best option with a -11.3% reduction vs 2019 (-18.4% against Baseline).

Figure 14 illustrates the role of thermodynamic efficiency as an engine of the additional economic growth. This indicates how much thermodynamic efficiency must increase if the higher GDP growth (see Section 4.2) is to be achieved. This is discussed later in the conclusions in Section 5.

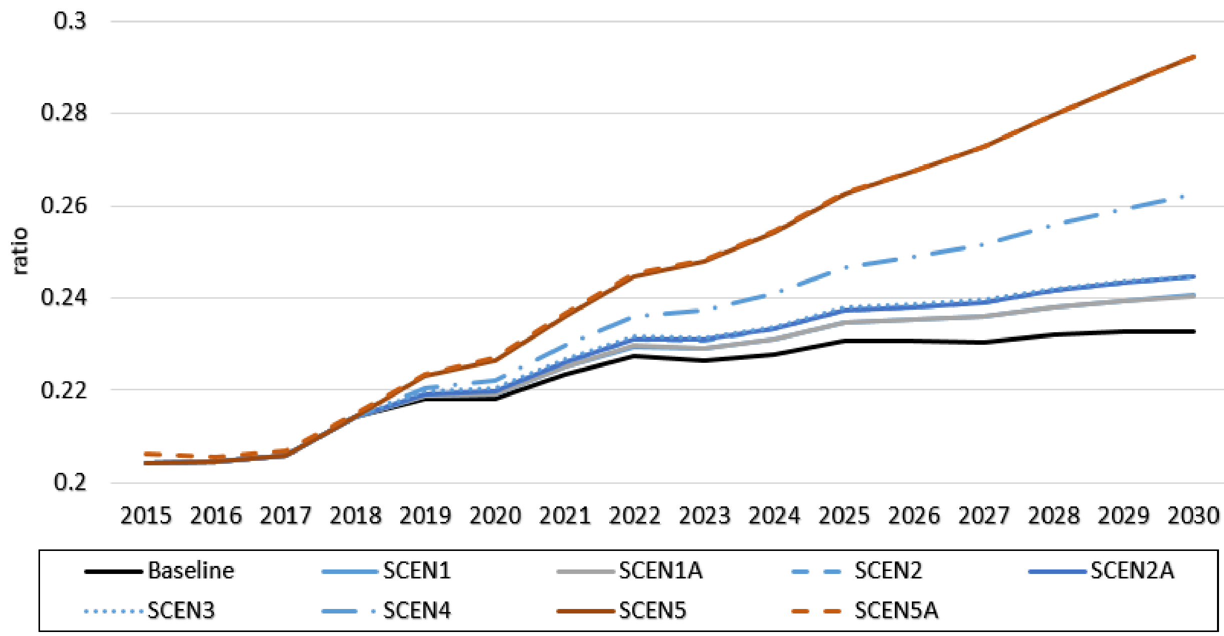

Figure 14. Thermodynamic efficiency by scenarios

4.2 GDP and productivity

To start, Figure 15 shows the GDP results. As the energy analysis may have suggested, scenarios that only account for energy savings as if no actions were required to produce them, show little socioeconomic impacts (SCEN1 and SCEN2). This is due to the relatively low weight of energy consumption in monetary terms compared total GDP. Although conventional knowledge states that energy savings lead to a households' budget increase that eventually would boost GDP, total households' energy consumptions represents 1.6% of GDP. Therefore, by liberating only a small fraction of that proportion to other expenditures makes for a small economy-wide impact. However, this energy saving encompasses investments both in new build and retrofit. So, in MARCO-UK this represents a demand-side shock that increases GDP which, in turn, raises the government earnings and allows higher government expenditure (maintaining its share over GDP constant). This triggers a multiplicative effect that enables the model to capture the real overall macroeconomic impacts of the BET.

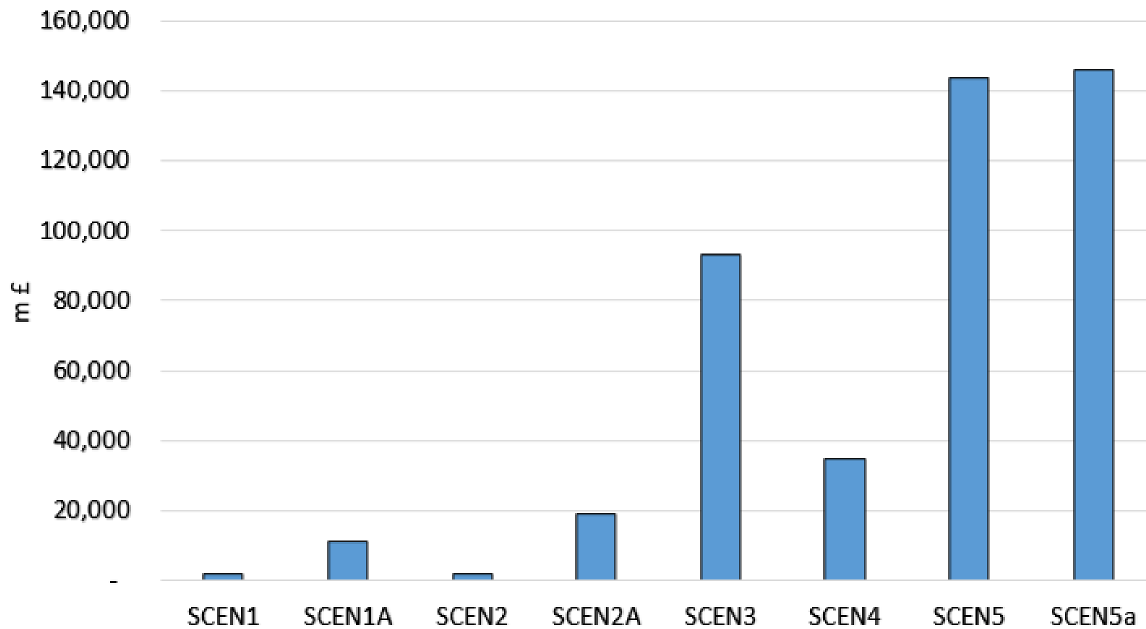

Figure 15. Cumulative additional GDP vs Baseline 2020-2030.

Another mechanism whereby MARCO-UK is able to capture the energy-economy interaction is via increased energy services. As the BET's actions are gradually installed, it would deliver energy efficiency gains that enable the useful exergy or energy services to increase. As a result, GDP would be able to grow faster in these scenarios. The policies applied by the BET would allow the GDP to grow above the BL projections in all scenarios. Total additional GDP measures the yearly extra GDP that is produced above Baseline. Here we see that SCEN3, despite its lower capacity to reduce energy use compared to SCEN4, generates more than double the GDP increase. This is mainly due to the higher level of investment – along with government expenditures – the main driver of the GDP increase (both directly and through the increase in useful exergy). As expected, SCEN5 is the scenario with the highest additional GDP prospects. In this scenario, nearly £150bn will be added to GDP during the decade. This represents nearly 7% of one year's GDP.

Figure 16 shows the ratio between the additional GDP generated and the aggregate funding required to implement the BET. For interpretation, a ratio of 1.40 means that meeting the BETs would yield 40% more benefits than the costs incurred.

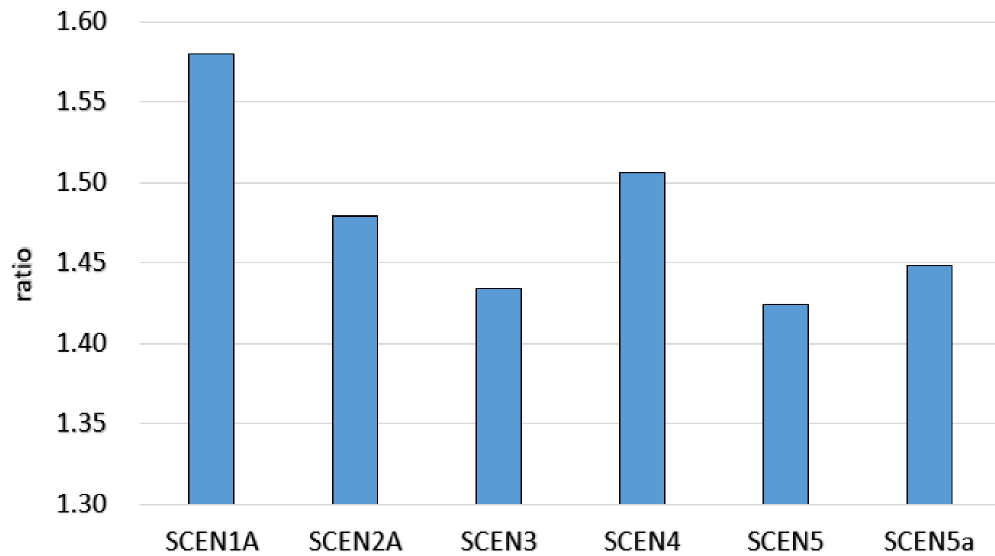

Figure 16. Additional GDP per £ invested

All scenarios show a relatively high capital-to-investment ratio (from 1.42 to 1.58). In SCEN3, SCEN4, SCEN5 and SCEN5a, this is because the 40% of the funding is provided by government expenditure. This is directly spent, not feeding a profitability-demanding capital stock. Therefore, the counterbalancing feedback is softened and the return ratio is higher. This adds consistency to the analysis, given that minor home improvements are not considered investment according to the Blue Book, and also due to the fact that domestic improvements do not need to be as profitable as if they were a new factory.

As the small GDP gains obtained in SCEN1a are mainly explained by the energy reduction and accounts with a relatively small investment effort, this scenario reaches the highest investment to GDP ratio (1.58). The other scenarios present an average of 1.46, standing out SCEN4 with a ratio of 1.51. This is achieved with a relatively low investment (£23Bn) compared to SCEN3 (£65 bn and 1.43 ratio) and SCEN5/5a (£100Bn and 1.42-1.45 ratio). Though SCEN3 and SCEN5 have higher investment, the large increase in capital investment leads to counterbalancing feedbacks in the mid-term, and the larger the investment is, the more intense the feedback is. Capital investment is a flow that feeds a capital stock that needs to be profitable. If this capital stock grows at a higher rate than historically, the economy is unable to absorb rapidly enough all the profits this new installed capital demands. As a result, GDP growth slightly slows down at the end of the period.

Finally, enhancing labour skills (SCEN5a) delivers a higher capital-to-investment ratio if compared with SCEN5. Although both scenarios account with same level of investment, the increased labour skills expands GDP via higher wages, leading to a boost in total consumption.

The mentioned feedbacks, previously described in section 2.2., make the trajectory of outcomes unevenly distributed along the simulation period. Figure 17 shows the yearly additional GDP by scenarios. It can be seen that for the scenarios with significant capital investment such as SCEN3, SCEN4, SCEN5 and SCEN5A, their gain versus the Baseline results starts to decline after a few years. Moreover SCEN3 and SCEN4, which have the larger share of government expenditures in total costs under the BET scenarios (40%), prove to be more resilient than e.g. SCEN5 and SCEN5A. This trajectory is reflected in all the socioeconomic variables, although for the sake of clarity, the average effects have been shown instead.

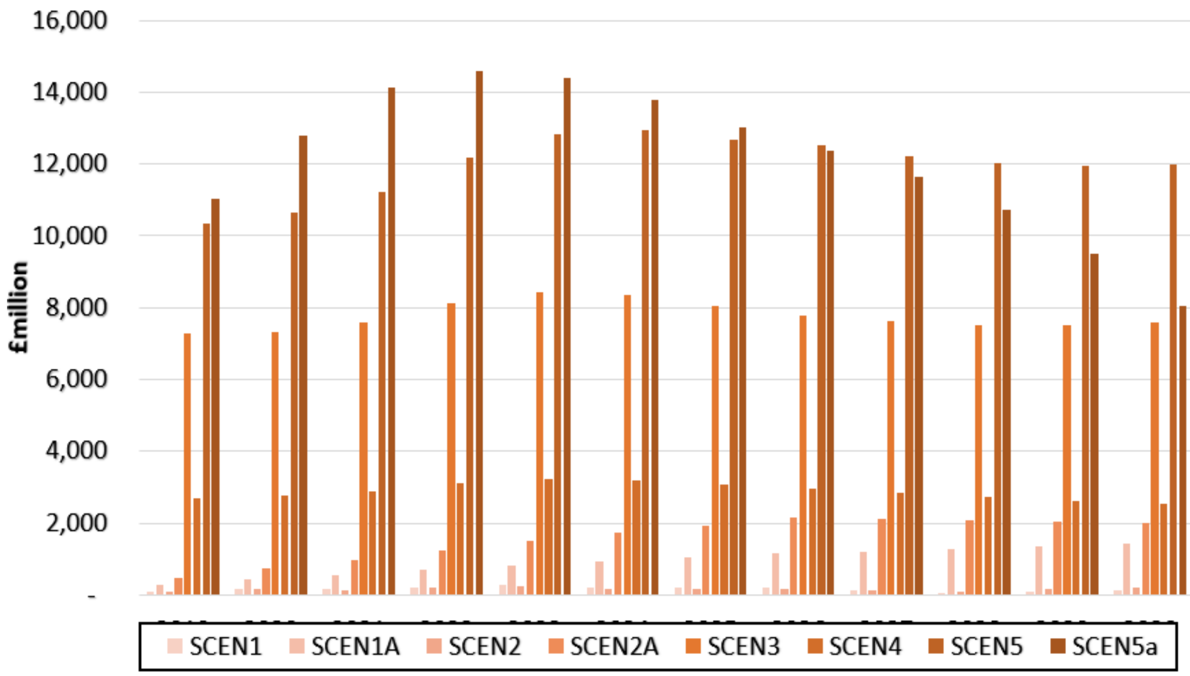

Figure 17. Yearly additional GDP over Baseline

Finally, the inclusion of the realistic assumption that the additional employment would be of higher skills (SCEN5a) would push the return rate to be the second highest among scenarios. Higher skilled workers imply higher total wages (see below) and higher useful exergy to provide energy services, both having positive effects on consumption and eventually, GDP.

Regarding productivity, we focus first on energy. Largely through reductions in final energy use, energy productivity rises in all scenarios. By comparing SCEN1 and SCEN2 with SCEN1a and SCEN2b, we can see that investments are crucial to produce these energy productivity gains. In addition, SCEN3 shows that the effects of just retrofitting homes would have little impact on this variable. Again, SCEN4 shows the relevance of the non-domestic buildings retrofit, since it is the scenario in which energy productivity grows faster, only behind SCEN5. Although investments are higher in domestic retrofit compared to non-domestic (£65 bn vs £23bn), the energy reduction capacity is higher in the latter (-11.2% vs -18.4%, both against baseline). Nevertheless, SCEN3 has other positive impacts compared to SCEN4 that are described later.

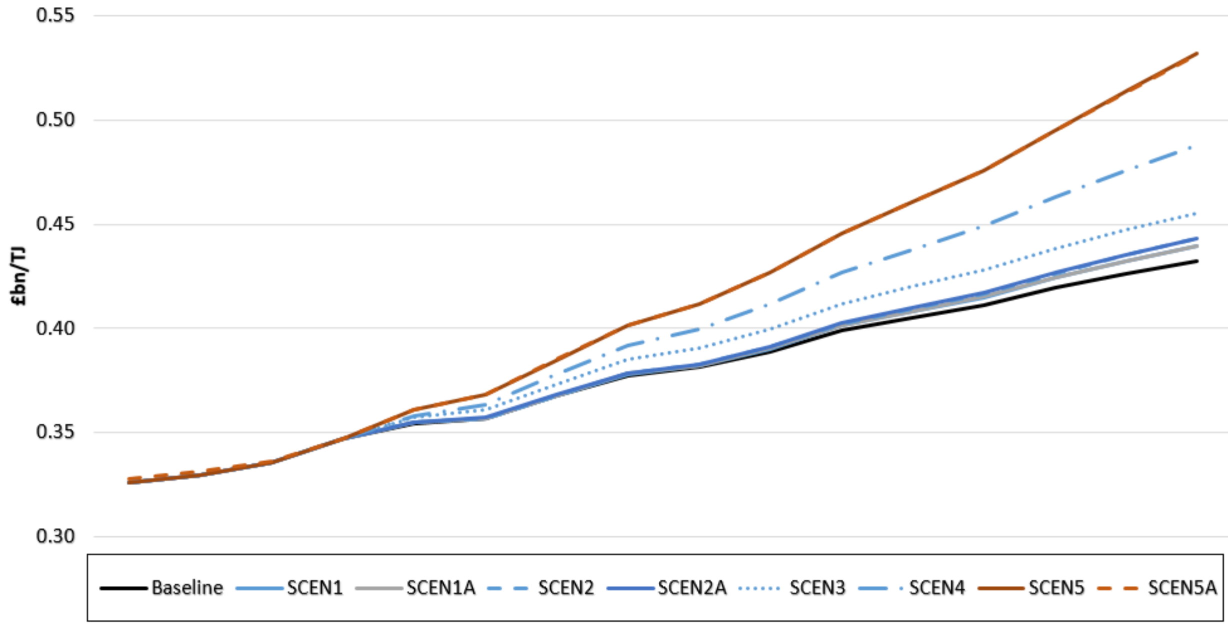

Figure 18: Final Energy Productivity (GDP/Total Final Energy use)

Another measure of productivity: labour productivity - measured as the GDP generated per worker, is shown in Figure 19. Labour productivity, as mentioned before, has been kept at Baseline level in SCEN1/1a and SCEN2/2a. Nevertheless, it can be seen that labour productivity would slightly increase in all other scenarios. SCEN5 shows the greatest average labour productivity improvement during the simulation period (+0.3% annual average 2019-2030). This is due to the higher proportion of government expenditures in this scenario, which lowers the counterbalancing feedback produced by the capital stock increase.

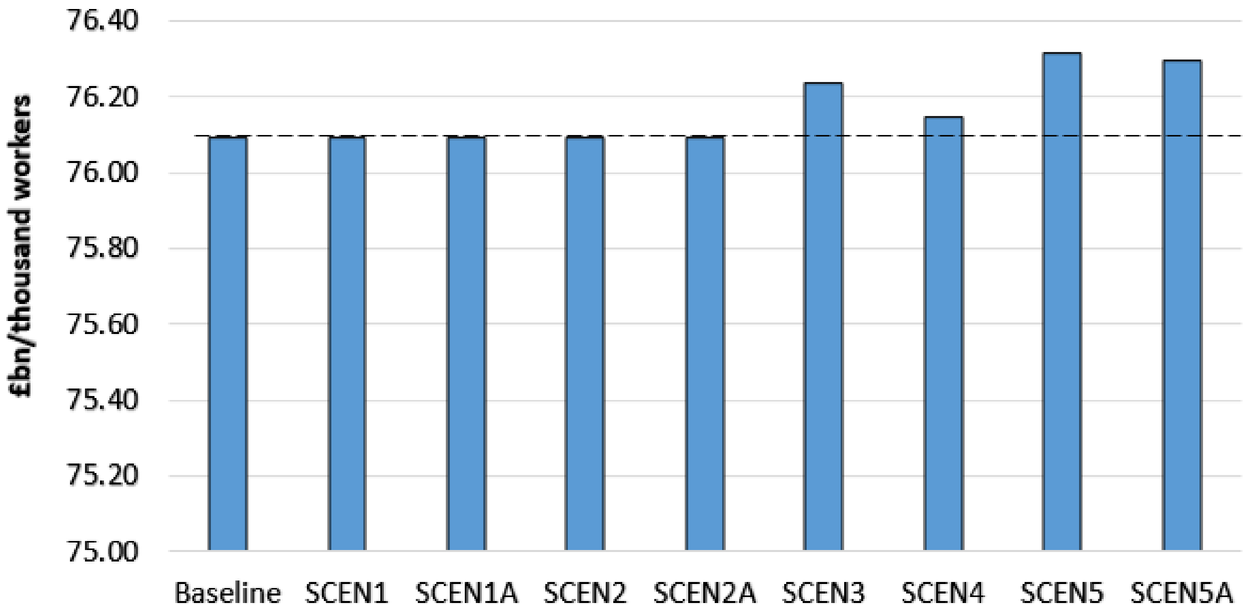

Figure 19. Labour productivity (GDP/L) by scenarios (average annual, 2019-2030)

4.3 Jobs and unemployment

The BET scenarios show that as long as investments are undertaken, jobs would be created. As mentioned earlier, employment is not a stock that can be accumulated. Consequently, MARCO-UK reports the total yearly employment in each scenario, which can be above or below the yearly total employment in Baseline. In order to assess the employment effects of the BET scenarios, the difference between employment in each scenario and in Baseline is estimated. As explained in section 3.1, and shown in Figure 19, the same labour productivity has been considered in both SCEN1 and SCEN2 to calculate total employment. Although the difference is not constant along the period, in order to facilitate the comparisons between scenarios, the average yearly difference is shown in Figure 20.

As seen before, only the scenarios with investments deliver significant socioeconomic effects. Despite the better performance of SCEN4 (non-domestic retrofit) in terms of energy reduction and GDP gains, it is the scenario where less employment would be created. This is mainly due to the fact that it has lower investment than SCEN3 and SCEN5. Moreover, SCEN5 would be able to create more jobs than SCEN2a, SCEN3 and SCEN4 all together (the same scenarios of which it is a combination of). The multiplicative effect generated by the demand-side shock, both capital investment and government expenditures, enables higher jobs growth. Additionally, by adding increased labour skills of the new labour force employed, the numbers of jobs created, on average, would be even higher in SCEN5a. This is due to the combined effects of increased wages and higher GDP growth.

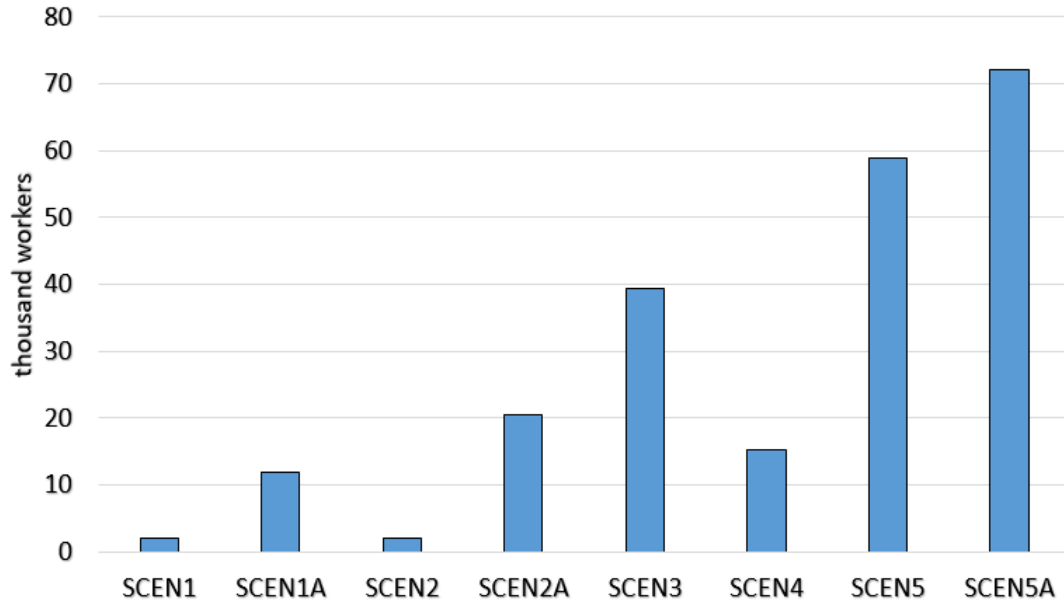

Figure 20. Average total annual additional jobs by scenarios

As an immediate consequence, given that population growth is the same across the scenarios, the average unemployment rate (2020-2030) would fall more intensely in SCEN5 and SCEN5a (see Figure 21).

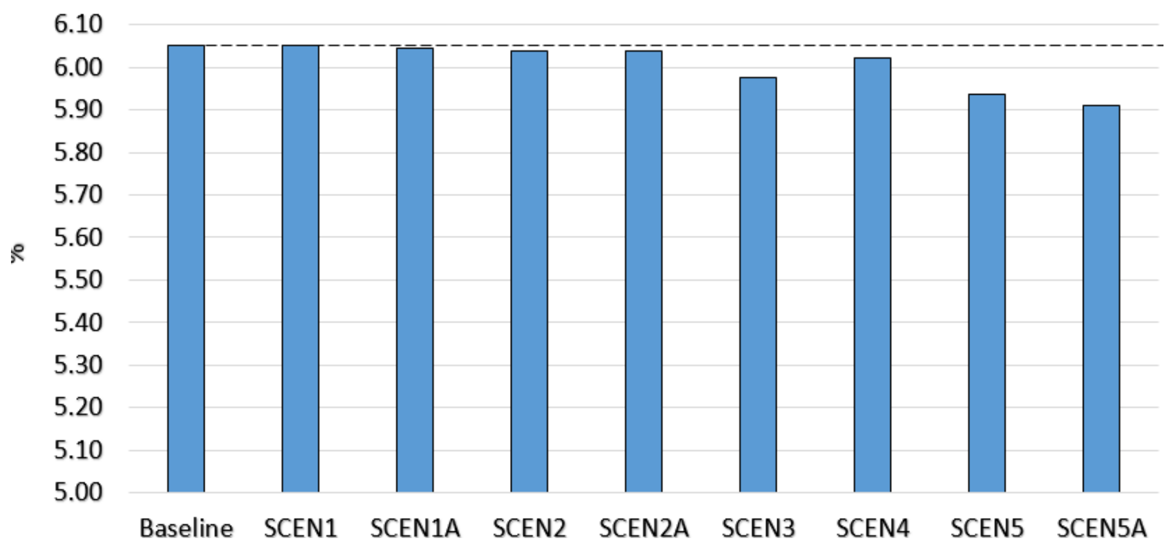

Figure 21: Unemployment Rate (Average 2020-2030).

4.4 Wages and disposable income

Total wages are defined as the sum of all the wages earned by workers across the whole economy. As wages are a yearly flow of income, it is more meaningful to look at the cumulative additional wages generated over the whole period. For this reason, Figure 22 shows the summation of total yearly additional wages, as the difference of the variable in each scenario versus the Baseline value, from 2019-2030. The same metric has been applied to Disposable income. Conversely, hourly wages are expressed as the ratio between total wages and the total amount of hours worked economy-wide. Hence, it would not make sense to express the results in terms of the total accumulated throughout the period. Rather, to facilitate the comparison between scenarios, the period's average has been taken.

Total wages are only able to increase if investments are made. The larger the investment is, the higher the total wages increase will be. Additionally, SCEN5a, i.e. the labour skills upgrade, enables an even higher rise of total wages. As aforementioned, this is due to the direct effect on hourly wages, but also to the increase in thermodynamic efficiency that eventually leads to GDP growth. As a consequence, employment also grows (see previous section) and therefore total wages also are boosted. Interestingly, the rise in total wages is mostly due to the additional employment created rather than an improvement in hourly wages.

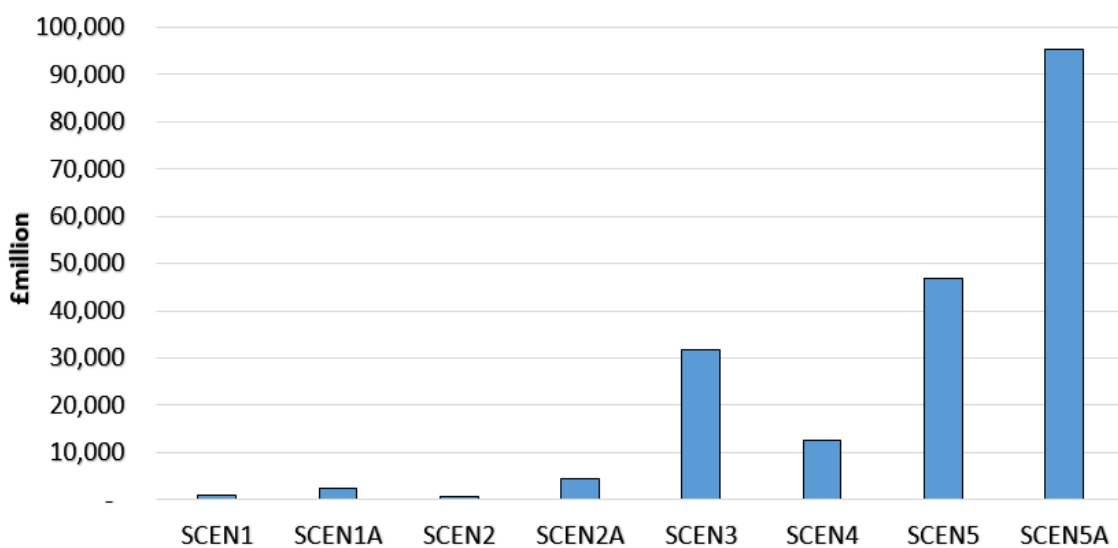

Figure 22. Additional cumulative wages over Baseline (2019-2030).

In fact, as shown in Figure 23, annual hourly wages in SCEN5a see a small increase (equivalent to 0.6% averaged 2019-2030) compared to SCEN5. This is around the same proportion as the new high-skilled jobs created. As mentioned before, by upgrading the skills of such a small fraction of the total labour force, the aggregated impact is similarly small. Nevertheless, it has the benefit of showing what would be the macroeconomic effects of taking skills into consideration. Among scenarios, all of them outpace the Baseline hourly wage. But SCEN3, SCEN5 and SCEN5a stand out over the others. Again, the relatively better performance of SCEN3 compared to SCEN4 has to do with the higher investment committed to the actions undertaken.

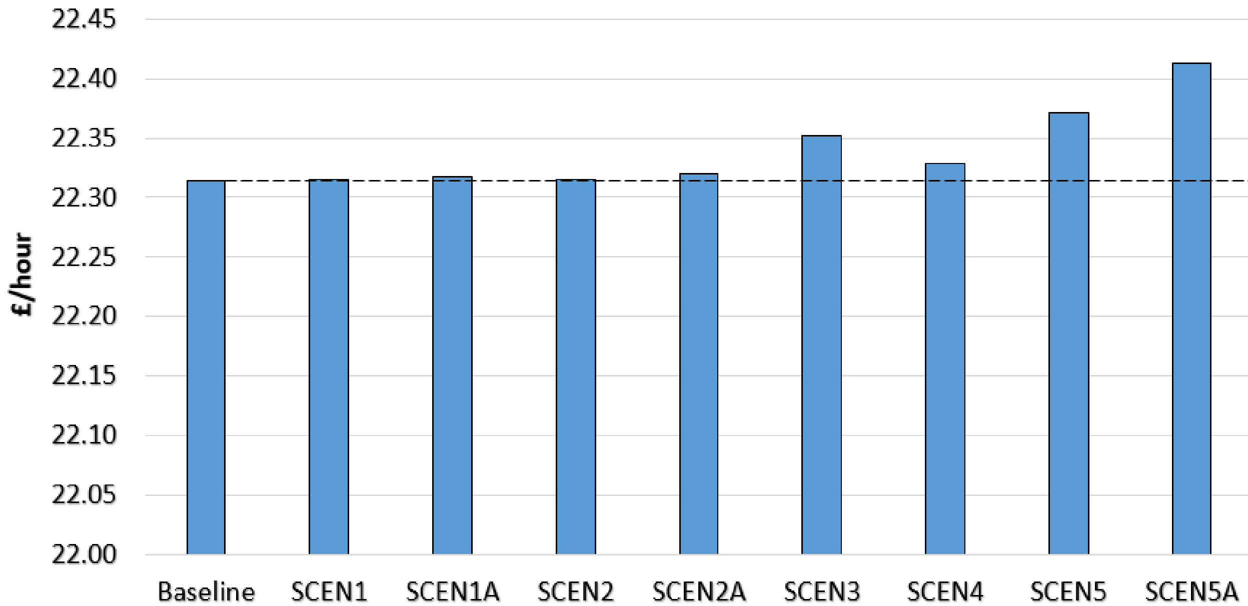

Figure 23: annual Hourly wages by scenarios. (Average 2019-2030)

Finally, as a reflection of the evolution of total wages, disposable income follows a similar path (higher wages = higher disposable income) for all the scenarios (see Figure 24).

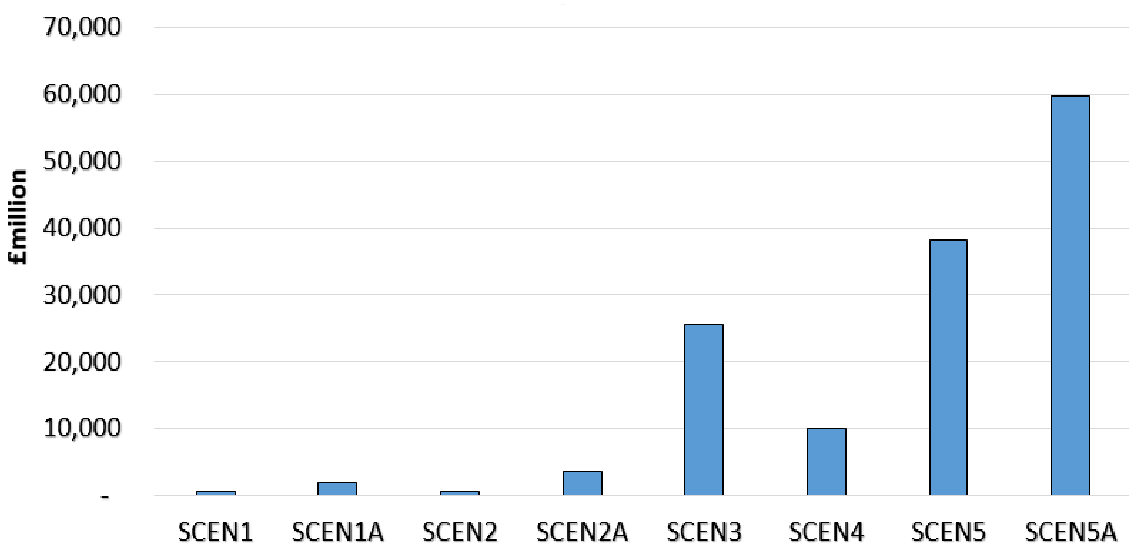

Figure 24. Total additional cumulative disposable income by scenarios (2019-2030)

4.5 Modelling limitations and assumptions

All these results must be interpreted with regards to the assumptions and limitations of macroeconometric modelling. Firstly, this relates to energy prices. Although there is a high energy efficiency increase and energy use by households reduces, the capital investment and government expenditures committed by the BET lead to an expansion of the economy. As a result, a rebound effect is triggered, pushing up energy use in other sectors and eventually increasing energy prices. In this analysis, this effect is not large, since there is only one remaining sector (industry) which is anyway decreasing its energy use. Despite the small effect on energy prices, energy prices have been kept at Baseline values in all scenarios. However, further actions would be required to deliver this price control. Moreover, without the split between capital investment and government expenditures, the secondary negative feedback from capital investment would have reduced the outcomes (see section 4) in SCEN3, SCEN4 and SCEN5. Although the division is based on literature, a thorough analysis might be required, should the BET be implemented, to correctly distribute this funding.

Secondly, are our assumptions regarding thermodynamic efficiency, which we allow to endogenously grow in the model in response to the demand-sided energy restriction - without imposing a thermodynamic limitation/ceiling. For information, final-to-useful exergy efficiency (thermodynamic efficiency) greatly increases in the scenarios where GDP grows the most. For instance, in SCEN5a, it grows 31.1% (2018-2030) whereas Baseline growth in the same period is 8.7%. For comparison, in the twelve preceding years (2006-2018), this variable grew by 4.9%. Therefore, should thermodynamic efficiency gains be constrained in the model (e.g. to avoid thermodynamically unfeasible results), such reduction of final energy use would in turn limit the gains in GDP (and other socioeconomic variables) shown in this report.

Thirdly, when reading the results of this particular analysis, that when a model variable changes its initial status, its role in the model also changes. Whenever an endogenous behavioural variable, such as capital investment, is exogenised, it stops receiving feedbacks in the simulation, precisely because it is now exogenous. It also has to be considered that this does not imply that the model is not able to account for these feedbacks, as is explained in section 2.2. For instance, the increase in government expenditure does not entail a continuous rise in all socioeconomic outcomes. Rather, as can be seen in Figure 5 in section 2.2.2, the trade balance could be harmed by an increase in domestic prices, and aggregate demand could be curtailed in the medium term, due to the shift in the employers' preference from labour to capital. Both situations may lead to a decrease in profitability that ends up harming private capital investment and, eventually, GDP, as can be noticed in Figure 6 (see sensitivity analysis in section 2.2.2) for the scenarios with increased government expenditure ('Y_G+10%', 'Y_G+20%', 'Y_G+30%').

5 Summary and Conclusions

The Building Energy Targets (BET) are aimed at reducing the energy use of domestic and non-domestic buildings, as a means to decarbonisation. In this analysis, several scenarios have been simulated with different policy targets and assumptions. SCEN1 and SCEN2 are focused on reducing new buildings' energy use. SCEN1a and SCEN2a simulated the same scenarios, but including the required capital investment to fund the actions carried out. All other scenarios include their respective funding requirements. SCEN3 and SCEN4 assessed a building retrofit strategy alone for existing domestic and non-domestic buildings respectively. SCEN5 combined SCEN2a,SCEN3 and SCEN4. Finally, SCEN5a is SCEN5 including an upgrade in labour skills.

We provide summary findings below:

Summary findings

1- Total Final Energy Use reduced in 2030 vs Baseline projection by -1.5% to -18.4% depending on the scenario.

2- Total Final Energy Use reduced in 2030 in absolute terms (vs 2019) in two scenarios: SCEN4 (-3.5%) and SCEN5 (-11.3%).

3- Average GDP growth to total investment ratio is 1.4-1.6 depending on scenario.

4- Building retrofit is more significant in socioeconomic terms (e.g. larger GDP growth, more jobs, higher wages) than new build.

5- A combination of all policies yields more economy and energy benefits than their sum (SCEN5 > SCEN2+SCEN3+SCEN4) due to multiplicative effects.

6- All the policies act as a source of employment creation, especially SCEN5 and SCEN5a (60,000 / 70,000 average additional annual jobs, respectively).

7- Accounting for the labour skills upgrade (SCEN5a) has overall positive effects at the macroeconomic level.

As a result of these scenarios, the MARCO-UK modelling outcomes reveal all scenarios would reduce total final energy use compared to Baseline, and in two scenarios (SCEN4 and SCEN5) absolute energy reductions are achieved versus 2019, reaching -11% in SCEN5 compared to 2019. This would be a consequence of the BET actions and the fact that the decrease in energy use by the industry sector is not interrupted due to the rebound effect of GDP growth. Moreover, the results also show that investments required would produce significant socioeconomic effects, with an appreciable return-on-investment (Additional GDP/Additional investment) ratio (1.4-1.6) across all scenarios. In addition, broader positive macroeconomic impacts also follow in these scenarios in relation to gains in employment and wages.

Whilst the labour market effects are not perhaps as significant as for instance, GDP gains, this is reflective of the macroeconomic model's empirical construction, where a historical long-term substitution effect between capital investment growth and relative decline in employment exists. However, the inclusion of an upgrade in labour skills would have additional potential to improve socioeconomic outcomes, avoiding negative feedback loops associated with the over-accumulation of capital in the economy. This would increase total wages and improve thermodynamic efficiency, both leading to additional consumption.

Overall, the targeted actions to achieve the BETs are shown by the MARCO-UK analysis to have the potential to play a key part in the next decade's reduction of absolute energy consumption in the UK, whilst releasing broader socio- and macroeconomic benefits. Whilst it represents a significant government and capital investment programme (around £100Bn), this is the scale of ambition required in order to meet future carbon budgets and meet the pathway to a Net Zero 2050 goal.

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Appendix A – summary detailed tables

More detailed data of the modelling outcomes can be seen in Tables 7-10 below:

Table 7. Scenarios outcomes. Absolute values in 2030

Variable	Code	Units	Baseline	SCEN1	SCEN1A	SCEN2	SCEN2A	SCEN3	SCEN4	SCEN5	SCEN5A
Total final energy use	**FEN_T**	TJ	6,685,751	6,579,959	6,580,008	6,527,083	6,527,135	6,368,091	5,935,283	5,455,459	5,454,376
Employment	**L**	'000s	35,510	35,511	35,527	35,512	35,534	35,515	35,511	35,515	35,516
Unemployment rate	**UR**	%	5.12	5.12	5.12	5.13	5.13	5.15	5.13	5.17	5.16
Wages	**W**	m £	1,438,167	1,438,238	1,438,572	1,438,213	1,438,933	1,440,853	1,439,276	1,442,454	1,457,442
Hourly wages	**W_ HOUR**	£/hour	25.45	25.46	25.46	25.46	25.47	25.52	25.48	25.55	25.69
GDP	**Y**	m £	2,891,232	2,891,339	2,892,646	2,891,439	2,893,241	2,898,821	2,893,756	2,903,206	2,899,281
Disposable income	**YD**	m £	1,911,245	1,911,329	1,911,646	1,911,301	1,912,051	1,913,965	1,912,354	1,915,654	1,921,828
Labour productivity	**Y_L**	m £/'000s workers	81.42	81.42	81.42	81.42	81.42	81.62	81.49	81.74	81.63
Energy productivity	**Y_E**	m £/TJ	0.43	0.44	0.44	0.44	0.44	0.46	0.49	0.53	0.53
Thermodynamic efficiency	**EXEFF 2_FU**	ratio	0.233	0.241	0.241	0.245	0.245	0.245	0.262	0.292	0.292

Table 8. Scenarios outcomes. Change (%) 2030 vs 2019

Variable	Code	Baseline	SCEN1	SCEN1A	SCEN2	SCEN2A	SCEN3	SCEN4	SCEN5	SCEN5A
Total final energy use	**FEN_T**	8.71%	6.99%	6.99%	6.13%	6.13%	3.54%	-3.49%	-11.30%	-11.31%
Employment	**L**	12.67%	12.67%	12.72%	12.68%	12.75%	12.68%	12.67%	12.69%	12.69%
Unemployment rate	**UR**	-24.26%	-24.25%	-24.28%	-24.14%	-24.14%	-23.89%	-24.10%	-23.56%	-23.69%
Wages	**W**	42.57%	42.58%	42.61%	42.58%	42.65%	42.84%	42.68%	43.00%	44.48%
Hourly wages	**W_ HOUR**	32.26%	32.27%	32.31%	32.27%	32.36%	32.58%	32.39%	32.78%	33.48%
GDP	**Y**	35.45%	35.46%	35.52%	35.46%	35.54%	35.81%	35.57%	36.01%	35.83%
Disposable income	**YD**	42.24%	42.24%	42.27%	42.24%	42.30%	42.44%	42.32%	42.56%	43.02%
Labour productivity	**Y_L**	20.22%	20.22%	20.22%	20.22%	20.22%	20.52%	20.32%	20.70%	20.53%
Energy productivity	**Y_E**	24.60%	26.61%	26.67%	27.64%	27.72%	31.16%	40.48%	53.33%	53.16%
Thermodynamic efficiency	**EXEFF2_FU**	8.73%	12.29%	12.29%	14.16%	14.15%	14.27%	22.51%	36.55%	36.23%

Table 9. Scenarios outcomes. Change (%) against Baseline in 2030

Variable	Code	Baseline	SCEN1	SCEN1A	SCEN2	SCEN2A	SCEN3	SCEN4	SCEN5	SCEN5A
Total final energy use	**FEN_T**	0.00%	-1.58%	-1.58%	-2.37%	-2.37%	-4.75%	-11.22%	-18.40%	-18.42%
Employment	**L**	0.00%	0.00%	0.05%	0.01%	0.07%	0.01%	0.00%	0.02%	0.02%
Unemployment rate	**UR**	0.000	-0.001	0.000	-0.009	0.000	-0.017	0.000	-0.037	0.000
Wages	**W**	0.00%	0.00%	0.03%	0.00%	0.05%	0.19%	0.08%	0.30%	1.34%
Hourly wages	**W_ HOUR**	0.00%	0.01%	0.03%	0.00%	0.07%	0.24%	0.10%	0.39%	0.92%
GDP	**Y**	0.00%	0.00%	0.05%	0.01%	0.07%	0.26%	0.09%	0.41%	0.28%
Disposable income	**YD**	0.00%	0.00%	0.02%	0.00%	0.04%	0.14%	0.06%	0.23%	0.55%
Labour productivity	**Y_L**	0.00%	0.00%	0.00%	0.00%	0.00%	0.25%	0.08%	0.40%	0.26%
Energy productivity	**Y_E**	0.00%	1.61%	1.66%	2.44%	2.50%	5.26%	12.74%	23.06%	22.92%
Thermodynamic efficiency	**EXEFF2_FU**	0.00%	3.28%	3.27%	5.00%	4.99%	5.10%	12.68%	25.59%	25.60%

Table 10. Scenarios outcomes. Compound annual average growth rate (CAAGR) (%) 2030 vs 2019

Variable	Code	Baseline	SCEN1	SCEN1A	SCEN2	SCEN2A	SCEN3	SCEN4	SCEN5	SCEN5A
Total final energy use	**FEN_T**	0.76%	0.62%	0.62%	0.54%	0.54%	0.32%	-0.32%	-1.08%	-1.09%
Employment	**L**	1.09%	1.05%	1.09%	1.05%	1.10%	1.04%	1.09%	1.04%	1.09%
Unemployment rate	**UR**	-2.49%	-2.49%	-2.50%	-2.48%	-2.48%	-2.45%	-2.48%	-2.41%	-2.43%
Wages	**W**	3.28%	3.25%	3.28%	3.25%	3.28%	3.27%	3.28%	3.29%	3.40%
Hourly wages	**W_ HOUR**	2.57%	2.58%	2.58%	2.57%	2.58%	2.60%	2.58%	2.61%	2.66%
GDP	**Y**	2.80%	2.80%	2.80%	2.80%	2.80%	2.82%	2.81%	2.84%	2.82%
Disposable income	**YD**	3.25%	3.26%	3.26%	3.26%	3.26%	3.27%	3.26%	3.28%	3.31%
Labour productivity	**Y_L**	1.69%	1.69%	1.69%	1.69%	1.69%	1.71%	1.70%	1.72%	1.71%
Energy productivity	**Y_E**	2.02%	2.17%	2.17%	2.24%	2.25%	2.50%	3.14%	3.96%	3.95%
Thermodynamic efficiency	**EXEFF2_FU**	0.76%	0.87%	1.06%	1.00%	1.21%	0.98%	1.86%	2.49%	2.85%

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