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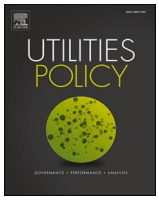

Full-length article

The sustainable economic growth implications of expanding the electricity network: can early investment reduce consumer costs and support greater GDP and jobs gains?

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ABSTRACT

In 2024, the UK Government introduced a statutory 'Growth Duty' on the energy industry regulator Ofgem. One implication is that industry actors must explain how proposed investments might enable sustainable economic growth processes when submitting their business plans as part of the regulated energy price control system. The first instance of this requirement affected the three GB electricity transmission owners (TOs) when submitting business plans in late 2024 for the RIIO-T3 period, which will run from April 2026 through to March 2031. This paper reports results and insights from independent research drawing on the investment plans of one of the three TOs in a set of economy-wide scenario simulations using a dynamic computable general equilibrium (CGE) model of the UK economy. A central finding is that our results indicate that undertaking early, planned investment at pace in anticipation of projected rising electricity demand, in response to the UK Government's electrification policies, is likely to deliver substantially stronger GDP and employment outcomes than a reactionary investment approach. This outcome is due to both an increased scale of earlier investment and the early creation of some excess capacity, which introduces downward marginal pressure on electricity bills. Moreover, where the latter is sufficient to offset the user bill impacts of investment cost recovery, the net outcome for UK households becomes progressive. The commonly expected outcome of cost recovery through energy bills being regressive does, however, manifest if electricity prices do not adjust in a competitive manner.

1. Introduction

A number of countries have clearly set, or in the case of the UK, formally written into law (Department for Business, Energy and Industrial Strategy, 2019), ambitions to transition to a net-zero economy by 2050. To achieve these ambitions, it is essential to decarbonise numerous activities and services that currently rely on fossil fuels. Notable examples include heating and transportation, where natural gas and refined petroleum products are the primary fuels used to deliver these services.

In the UK, existing strategy documents, such as the Heat and Buildings Strategy (Department for Business, Energy and Industrial Strategy, 2021), clearly indicate that the government favours decarbonisation, at least for residential heating and private transportation, via electrification. Moreover, the Clean Power 2030 plan sets an objective of sufficient electricity generation from low-carbon sources to (at minimum) meet Great Britain's (excluding Northern Ireland) annual consumption requirements, while accounting for 95 % of Great Britain's generation by 2030 (DESNZ, 2024).

The associated widespread shift from fossil fuels to low-carbon electricity is expected to lead to a significant increase in electricity demand in the years to 2050, as reflected in projections published by the GB energy system operator (National Energy System Operator, 2023a). In response to policy ambitions on both the supply- and demand-side, and to enable the projected increase in electricity demand, in late 2024, the transmission network operators submitted investment plans for consideration by the GB's energy market regulator, Ofgem, as part of the upcoming price control period, RIIO-T3.

In 2024, a UK parliamentary committee – the Environmental Audit (EA) Committee – issued advice to the Government on the necessity to resolve challenges around slow grid connections and unclear energy storage plans to achieve successful and timely electrification of the wider UK energy system, where failing to do so means a real risk of failing to meet net zero targets (House of Commons, 2024). The

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committee advised that the Government and Ofgem should place greater emphasis on reforming connections and ensuring the provision of transmission capacity linked to new energy developments.

Historically, Ofgem has limited the network operators' ability to invest ahead of demand, aligned with the regulator's remit. However, in the current price control period for the distribution network, RIIO-ED2, network operators can invest in anticipation of projected demand (Ofgem, 2020). More recently, Ofgem's multi-year strategy document sets specific objectives to enable infrastructure development at pace (Ofgem, 2024a). Although this is a welcome development for energy project developers and network operators, the question remains: how will the cost of the multi-billion-pound investments be recovered, and how may this be affected by anticipatory rather than responsive investment? The current approach of Ofgem aims to keep costs "to a minimum" (NIC, 2025), with the concern being that anticipatory investment at pace could lead to increased burdens on consumers and the wider UK economy, with a risk of creating stranded assets, as compared to one where electricity industry investment reacts to changing demand. However, a reasonable economic hypothesis would be that enabling supply to move ahead of demand may enable a lowering of the cost-price burden.

Here, we test this hypothesis by employing a computable general equilibrium (CGE) approach to simulate scenarios involving the RIIO-T3 investment plans of one of the three GB Transmission Owners, SP Energy Networks, whose investment plans we were given access to prior to the public publication (Energy Networks, 2024). We use this case study to consider the research question of how the timing of investment on the nation's electricity network, with specific attention to whether an anticipatory or reactionary approach to projected rising demand for electrification (with investment costs recovered through user bills) is employed, is likely to lead to different economy-wide and distributional outcomes, including through the net impact on user bills. This policy-facing question is timely, as since May 2024, Ofgem has a statutory growth duty, meaning that they are required consider how their regulatory decisions may affect the growth potential of the UK economy (DBT, 2024).

Specifically in this work, we are looking to answer the following underlying research questions:

- What are the differences in economy-wide impacts and drivers thereof, across scenarios for anticipatory or reactive network investment, where substantial increases in electricity demand trajectories are projected?
- How are outcomes affected if electricity demand does not manifest as projected?
- What are the implications if price-setting behaviour means that electricity prices do not smoothly adjust to changes in network supply capacity?

A dynamic computable general equilibrium (CGE) scenario simulation approach is employed, on the basis that CGE models capture the mechanisms by which costs and prices in different markets respond to changes in activity and the likely impacts on both sectoral and macroeconomic activity. Crucially, the activity involved in extending the electricity network will have implications for labour demand in the UK's persistently supply-constrained labour markets. Crucially, changes in nominal wages paid by producers and real wage returns to UK households may play an important role in determining economy-wide outcomes alongside the more direct impacts of energy prices and bills.

Our central case findings suggest that a key driver of sectoral and macroeconomic outcomes is the timing of investment, which affects the electricity prices and user bills. Specifically, our central scenario findings indicate that investing at pace in anticipation of projected rising demand has the potential to drive a slight, yet sustained, decrease in energy bills. This helps mitigate not only the user bill impacts of investment cost recovery, but also upward price pressures associated with increased electricity demand and activity levels, as well as the cost pressures triggered in the constrained labour market. In contrast, a reactionary investment approach tends to exacerbate upward pressure on energy bills and these wider cost pressures, thereby eroding potential net gains at sectoral and macroeconomic levels.

Sensitivity analyses reveal two important qualifications on our findings. First, important trade-offs emerge where an anticipatory investment approach is adopted if demand does not materialise as projected. This equates to a situation where excess electricity network capacity is created, which will further reduce energy bill pressure but will also reduce the returns to the capital created, reflecting the accepted risk of stranded assets. A more general source of sensitivity in our results arises when electricity prices do not adjust smoothly to changes in supply and demand. Again, this is particularly the case with anticipatory network investment, where an important driver of net economic gains is removed, with implications for sectoral and macroeconomic outcomes across all timeframes.

The remainder of the paper is structured as follows. Section 2 discusses the existing literature and the contribution of our work. In Section 3, we present the key characteristics of our methodology and our simulation strategy. Our central case scenario results are presented and discussed in Section 4, along with our focused sensitivity analyses. Section 5 concludes and identifies future research directions.

2. Contribution to the literature

Electricity networks, and the electricity transmission network in particular, have been the focus of academic research over several years and from different viewpoints. From bottom-up techno-economic modelling to determine the size of the investment requirements to the European electricity transmission network (e.g. Egerera et al., 2016), to research looking at the potential competitiveness benefits from the expansion of electricity networks (e.g. Bresesti et al., 2009; Zerrahn and Huppmann, 2017).

There is further work that explores the transmission and distribution investment decision-making processes, in the face of uncertainties emerging from the expansion of distributed generation or the increased electrification of different services (e.g. Borozan et al., 2022; Moya et al., 2022; Ruiz and Conejo, 2015; Silvestro et al., 2019). Moreover, research has examined the opportunity costs of prioritising investment in transmission capacity over generation capacity expansion, and vice versa (Alayo et al., 2017).

Among the work exploring the economic implications of electricity networks, two broad themes emerge. The first focuses on the impacts of electricity losses and disruptions in electricity supply to the economy and the associated costs. For instance, Costa-Campi et al. (2018) quantify electricity losses in continental Spain's electricity network and the associated costs from both a consumer and a generator perspective. Wing and Rose (2020) develop a stylised general equilibrium model to examine the economy-wide losses from power outages, focusing on California. Similarly, Fried and Lagakos (2023) employ a simple general equilibrium framework to study the implications of disrupted electricity supply on the productivity of firms, focusing on the Sub-Saharan African economies of Ethiopia, Ghana, Nigeria, Tanzania, and Uganda.

The other broad theme focuses on the economic impacts of expanding electricity networks. Where the literature focuses specifically on network expansion, we see a particular focus on developing economies. For example, Bos et al. (2018) provide a review of the available evidence on the potential benefits and challenges of expanding electricity networks, and through that access to electricity, in African countries. In a more specific example, Borojo (2015) uses a CGE model to explore whether expanding Ethiopia's electricity network can deliver economy-wide gains, focusing on GDP, sectoral output, household consumption, and the country's trade balance.

This focus on developing economies is not unexpected, given the sizable expansion of electricity networks required to allow nations to

develop. A review of the existing macro-economic evidence by Burke et al. (2018) suggests a strong correlation between electricity access and use and economic development. This finding is further reinforced by the work of Shakouri et al. (2023). Hence, there is significant research and policy interest in establishing and reinforcing the importance of increased electrification in supporting national development.

On the other hand, this also explains why relevant work focusing on developed economies tends to prioritise the study of economy-wide impacts of expanding domestic electricity generation; in general or with a particular focus on renewable generation. On this theme, Lekavicius et al. (2019) use a CGE model to examine the economy-wide impacts of increased domestic electricity production in Lithuania. Bachner et al. (2019) use a global multi-regional CGE model to explore the economy-wide implications of increased wind and photovoltaics generation capacity in Europe. Similarly, Chatri et al. (2018) study the economy-wide impacts of the expansion of renewable generation capacity in Malaysia – arguably a more advanced economy compared to the Sub-Saharan countries studied in other research outputs – again using a CGE modelling framework. A CGE modelling framework is also employed by Alabi et al. (2022) to study the economy-wide implications of electrifying private transportation in the UK.

Further expanding on the relevant literature with a UK focus, it can be seen that the research discussing the need for investment in energy-related infrastructures in order to achieve the UK's net zero ambitions does so from a decarbonisation of electricity supply and demand perspective, such as through the expansion of renewable generation or the electrification of residential heating (e.g. Geels et al., 2023; Olympios et al., 2022; Royapoor et al., 2023). Even in the work of Alabi et al. (2022), the network upgrade is considered as an enabler of electrifying private transportation rather than a driver of economic benefits in its own right. Notable exemptions are the reports by Bell (2022) and Daly et al. (2022), who consider, to some extent, the economic implications of network investments in the UK.

Reviewing the literature then reveals a clear gap in the study of the economy-wide impacts of electricity network investments in developed countries, including, but not limited to, the UK. Given the strong evidence of a correlation between electricity access and economic development in developing countries, it would be natural to explore whether similar outcomes, at least in nature, can be replicated through electricity network investments in developed countries. Furthermore, there is a distinct absence in the academic literature of analyses exploring the differences in investment pacing.

This paper makes a two-fold contribution to the existing literature. First, we add to the evidence base on the economy-wide implications of investing on the expansion of the electricity transmission network in a developed-economy context, here the UK. Second, we bring insight into how the economy-wide outcomes are likely to depend on whether network investment anticipates or responds to changes in electricity demand, with a focus on understanding the importance of different drivers, such as competitive pricing behaviour in energy supply.

Our choice of a CGE modelling framework aligns with the methodologies used in the literature to study the economy-wide impacts of energy-related developments. Beyond the academic contribution, the outputs of this work are also relevant to policy, regulatory, and industry audiences in the UK and other nations that are challenged by delivering the infrastructure required to support net-zero and clean power ambitions. Here, all UK regulators, including Ofgem, now have a statutory Growth Duty (DBT, 2024) requiring them, and regulated firms setting out business cases through processes like RIIO-T3, to explore how proposed actions/regulations are likely to contribute towards the sustained growth of the UK economy (Ofgem, 2024b). More generally, the work presented here speaks to the need for all decision makers in the public policy domain to identify and respond to potential unanticipated and/or unwanted consequences of transitionary actions.

3. Methodology and simulation strategy

3.1. The UKENVI model

We use a computable general equilibrium (CGE) model of the United Kingdom economy, UKENVI, informed by and calibrated to a social accounting matrix (SAM) for the most recent year for which appropriate economy-wide accounting data are available.[1] Here, this involves incorporating the 2018 industry-by-industry (IxI) input-output (IO) data available from the UK Office for National Statistics (ONS). Given the inherent time lag in producing comprehensive IO data – a common challenge in CGE studies – and avoiding years affected by the COVID pandemic and height of conflict in Ukraine, the 2018 SAM is utilised to represent the state of the UK economy in 2025, considering the 2026–2031 timeframe for the RIIO-T3 investment period. To maintain consistency with the data informing our model, we use the UK GDP deflators[2] to deflate all scenario inputs to our model to 2018 prices. We then inflate any monetary value results to 2023 prices for reporting purposes.

We aggregate UK production to 34 domestic sectors (detailed in Appendix B) and corresponding commodity imports, while preserving granular data on energy supply sectors and other sectors, such as Construction, relevant to this work.

Note that here we are concerned only with changes in the GB system, excluding Northern Ireland. In the absence of SAM data excluding that region (accounting for 3 % or less of the UK population and GDP), we model for the UK with a focus on investment activity for just one of three GB transmission operators. However, we note that there will be cost recovery impacts on NI households that will not occur in practice.

Turner et al. (2022) provide a more in-depth explanation of the variant of the UKENVI model used here. The following is a broad description of some of the model's main characteristics, with a focus on those relevant to the simulations conducted for this research. In Appendix A, we provide a listing of all the variables and parameters of the model, along with their default values, while Appendix B provides a schematic representation of the model's production and consumption structure and a listing of all the sectors.

3.1.1. Production and investment

The production structure in this CGE model employs a nested Constant Elasticity of Substitution (CES) function, a common approach in economy-wide research. Our model is structured so that labour and capital are combined in a value-added nest, while domestically produced and imported energy and non-energy goods and services are combined in an intermediate nest.

Each sector in our model produces a single output, which is used as input by other UK sectors, by UK final consumers, or is exported abroad. For each sector, the total absorption equation is:

$$X_{i,t} + M_{i,t} = \sum_{j} VV_{i,j,t} + \sum_{h} QH_{i,h,t} + QV_{i,t} + QG_{i,t} + E_{i,t} + EXO_{i,t} \quad (1)$$

Here, the sum of the sector's output (X) and the corresponding imports (M) must equal the sum of intermediate demand (VV), the different kinds of final demand (QH, QV, QG), the exports (E) and an exogenous demand factor (EXO) where relevant. For this work, the intermediate demand for electricity, let it be $INTele_{j,t}$, for simplicity, is particularly relevant and is calculated as follows:

[1] The UKENVI SAM is publicly available at: https://doi.org/10.15129/884b5286-bdb3-4eb9-bc47-08c77caf5f9e.

[2] The UK GDP deflators are available here: https://www.gov.uk/government/statistics/gdp-deflators-at-market-prices-and-money-gdp-march-2025-spring-statement-quarterly-national-accounts.

$$INTele_{j,t} = \left(A^{E\rho_j^E}\left(\delta_j^{INTele}\right)\cdot\frac{PE_t}{Pele_t}\right)^{\frac{1}{1-\rho_j^E}}\cdot INTEN_{j,t} \quad (2)$$

In (2), δ^{INTele} is a share parameter, while ρ^E is the elasticity of substitution between electricity and non-electricity energy goods in production. PE corresponds to the price of the composite energy good, P_{ele} is the price of electricity, and, finally, $INTEN_{j,t}$ is the total intermediate energy demand by sector j. It is clear, then, that the intermediate demand for electricity is affected by the price of electricity, which, in turn, is linked to total demand as expressed in (1).

It is important to highlight that this standard CGE treatment of a price determination through the market clearly is rather simplistic in the case of electricity, where the price paid involves both a fixed (standing charge) and variable (unit cost) element, and there are various interventions in practice (such as the Ofgem Energy Price Cap for residential consumers). Here, the model's electricity price effectively captures the variable component of the electricity price in an uncapped, fully competitive manner. We adjust here (see Section 3.1.4 below) for the recovery of investment costs, which, in the GB system, is reflected in the standing charge element of the electricity price. Here, we model this standing charge change as separate from, and in addition to, the market-determined output price of the electricity sector, so that the net impact thereon is better reflected in user bills.

The default specification for this version of our model incorporates a recursive dynamic process for capital stock adjustment across the 34 existing sectors, with investment determined endogenously. Investment in the 34 sectors covers depreciation and a portion of the gap between actual and desired capital stock:

$$I_{i,t} = \nu\left(KS^*_{i,t} - KS_{i,t}\right) + \delta KS_{i,t} \quad (3)$$

$$KS_{i,t+1} = (1-\delta)KS_{i,t} + I_{i,t} \quad (4)$$

In equation (3), I corresponds to the investment of each sector i in period t, while KS reflects the sector's actual capital stock in the same timeframe. KS^* corresponds to the desired capital stock, which is influenced by the level of demand for the outputs of sector i. Finally, δ is the capital depreciation rate, which is assumed to be fixed, and ν is an adjustment coefficient determining how quickly the actual capital stock converges to the desired capital stock. When investment is calculated endogenously for all sectors, (3) determines the level of investment each year, and by extension defines the actual capital stock of each sector in the following year under equation (4).

For our central scenarios, though, we employ a different specification for the Electricity sector, where the investment I_{ele} in year t is determined exogenously, using investment spending and asset creation data provided by one of the GB network operators, to model investment at pace.

$$I_{ele,t} = I0_{ele} + ExoI_{ele,t} \quad (5)$$

The implication of treating investment exogenously, as in (5), is that we have complete control over the evolution of the capital stock of the electricity sector. However, investment no longer responds to any endogenous changes in electricity demand, meaning the capital stock of the electricity sector remains fixed once the full shock has been introduced.

We abstract from endogenous technological advancements across the UK economy, as this would necessitate a comprehensive analysis of potential counterfactual scenarios involving various economic and policy developments and would unnecessarily complicate the elucidation of causality and results for the electricity network expansion scenarios considered. Therefore, all the results discussed in Section 4 are triggered exclusively by the scenarios we modelled, allowing a clear understanding of the underlying causal processes.

A key long-run equilibrium condition in the model stipulates that the actual capital stock should converge with the desired capital stock across all sectors. This equilibrium is achieved when investment is sufficient to offset capital depreciation, ensuring a stable economic structure in the long term and no further creation of production capital. For our central scenarios, we must exogenously set the long-run investment level to account for the depreciation of additional capital introduced by the scenarios.

3.1.2. Labour market

Our standard assumption for the UK economy is a fixed aggregate labour supply, deliberately excluding endogenous population growth. In the absence of sector-specific data on skills or occupations, we assume full labour mobility across sectors. In principle, this assumption eases the wage and associated economy-wide pressures that would emerge in a labour market characterised by limitations in the movement of workers between sectors. However, recognising the significance of labour supply constraints, we incorporate an imperfectly competitive labour-market treatment that involves workers moving between employment and a pool of unemployed labour in response to fluctuations in labour demand and changes in the UK's average real wage rate. This mechanism is captured through the implementation of a bargained real wage (BRW) function, drawing on the work of Blanchflower and Oswald (2009). By incorporating these labour market dynamics, we can capture the interactions between sectoral labour demand, wage adjustments, and overall employment level in response to investment, here, in the expansion of the electricity transmission network. The real wages in our model are calculated using:

$$\ln(w_R) = \omega - \varepsilon \ln(u_t) \quad (6)$$

The base year unemployment rate is 4.1 %, according to ONS data.[3] The wage-bargaining mechanism in the model captures the inverse relationship between unemployment and workers' bargaining power. This relationship is quantified by the parameter ε, which represents the elasticity of wages with respect to the unemployment rate. In the UKENVI model, ε is set at 0.113, drawing on the work of Layard et al. (1991) and Blanchflower and Oswald (2005), and, more recently, reinforced by Allan et al. (2021).

3.1.3. Households

Our model includes five household income quintiles, disaggregated by gross real income. Each quintile has its own composition of income, which is a combination of income from employment, income from capital, transfers from the government and firms, both fixed in real terms, as well as transfers from abroad at a fixed exchange rate. Each quintile also has its own fixed marginal propensity to save. Both the composition of income and the marginal propensity to save of each quintile are defined in the SAM, as is the initial distribution of their disposable income across domestically produced and imported goods and services. Beyond the base year, households are assumed to spend their entire disposable income, while the exact household consumption is determined by the relative prices of the different goods and services, subject to the elasticities of substitution.

For this work, the most relevant part of household consumption is the consumption of electricity, which is calculated as follows:

$$ELE_{h,t} = \left[\delta_h^{\rho^C}\left(\frac{CPI}{Pele_t}\right)^{\rho^C} C_{h,t}\right] + EXOQH_{h,t} \quad (7)$$

In (7), C is the total household consumption, also matching the disposable income of each quintile. ELE reflects the electricity consumption for each household income quintile, ρ^C is the elasticity of substitution

[3] The annual unemployment rate data are available at: https://www.ons.gov.uk/employmentandlabourmarket/peoplenotinwork/unemployment/timeseries/mgsx/lms.

between residential energy and other goods and services, δ^{pC} is a share parameter, and *EXOQH* is an element to exogenously shock the household consumption of electricity so that a projected increase can be modelled. It is also clear in (7) that the price of electricity, P_{ele}, also plays a key role in determining the level of electricity consumption.

3.1.4. Recovery of the network expansion cost

In the absence of any exogenous disturbance, the price of electricity, P_{ele}, in (2) and (7) is set at the marginal cost of electricity production and supply and therefore identical to the price, P_{elemc}, in a perfectly competitive market.

To model the recovery of network expansion costs, we use the approach employed by Alabi et al. (2022). This approach follows the current standard in the GB energy market, where the cost of expanding the transmission network is covered by all UK electricity users; households, industries, commercial businesses, as well as parts of the Electricity sector, such as the generators. Cost recovery is achieved by introducing a mark-up on the perfectly competitive market price of electricity. This method leads to a new common endogenous consumption price of electricity, P_{ele}, applied to all electricity users, which is calculated as follows:

$$Pele_t = Pelemc_t \cdot (1 + \theta_t) \tag{8}$$

In (8), θ is the mark-up introduced to the market price of electricity, meaning that the difference between the two prices is the marginal profit rate of electricity firms.

$$mp_t = Pele_t - Pelemc_t \tag{9}$$

Multiplying the marginal profit rate by total electricity sales revenue yields the total profit (*NTW*).

$$\overline{NTW_t} = mp_t \left(\sum\nolimits_h ELE_{h,t} + \sum\nolimits_j INTele_{j,t} + EXO_{ele,t} \right) \tag{10}$$

By setting the total profit equal to the annual recovery of the network expansion cost, the mark-up θ needs to appropriately increase to get the marginal profit required in order to recover the network expansion cost.

3.1.5. Government and trade

Government revenue comprises of income taxes (the largest component), other taxes such as indirect business tax, income from capital and foreign remittances at a fixed exchange rate. Government spending is assumed to be fixed in real terms, with nominal adjustments in line with the CPI for government transfers to firms and households, and adjustments to the cost of government consumption driven by the government's composite price of consumption. The government is not required to have a balanced budget as part of the long-run equilibrium conditions. Thus, the impacts of the network expansion are reflected in the government budget balance.

We assume that the UK trades with an external region with fixed prices across all timeframes. Therefore, changes in imports and exports depend on the UK price changes relative to the unchanged prices of externally produced goods and services. UK sectors and consumers use a combination of domestically produced and imported goods and services, with imports treated as imperfect substitutes for domestic goods and services under an Armington assumption (Armington, 1969). Exports to the external region are determined by a constant elasticity of transformation function. In the absence of detailed econometric estimates for this model, we rely on the elasticities from existing work using the UKENVI model. We set the default values of both the Armington and export price elasticities to 2, as in Turner (2009), benefiting from the extensive sensitivity analyses in that work regarding those elasticities. As with the government, we do not impose a trade balance as part of our long-run equilibrium conditions.

3.2. Simulation strategy and assumptions

3.2.1. The expansion of the transmission network and the cost recovery

In this work, we focus on expanding part of the UK's electricity transmission network. We use information now published by SP Energy Network in their RIIO-T3 Business Plan[4] to inform our scenarios, at this stage abstracting from considering the other two transmission network operators. This approach reveals that, in the following UK price control period, this TO plans to spend a total of £10.6 billion (in 2023/24 prices) on expanding the part of the UK transmission network they operate, as well as replacing existing equipment. The distribution of the spending across the Price Control period is shown in Table 1.

Of the total spending, £1.82 billion corresponds to the replacement of existing equipment, which is expected to involve primarily imported equipment. We cannot model the production of that equipment in our UK model, but this cost is included in the recovery of the total cost via energy bills. The remaining £8.82 billion is associated with the expansion and upgrade of the transmission network.

Through our engagement with the network operator, and taking into account the projected change in the regulated asset value (RAV) of their transmission network, their share of the total RAV of the transmission and distribution networks, as well as the size of the networks in comparison to the wider electricity sector, we estimate that the planned £8.82 billion spending will increase the size of the UK electricity sector by 4.89 %. These calculations are necessary because the UK IO tables underlying our model database only include a uniform electricity sector, encompassing generation, transmission, distribution, and retail. It was therefore necessary to scale the size increase accordingly so that we have a representative investment shock. The path of the network expansion through the price control period is shown in Table 1. We then introduce appropriate values in the exogenous investment of the electricity sector in equation (5), to ensure that the size of the sector's capital stock expands in line with the 'Accumulation of network expansion' in Table 1 and remains at that level until the long-run.

Regarding cost recovery, we follow the approach described in Section 3.1.4. An important point to note is that, in consultation with the network operators, we assume that 10 % of the total cost recovery is happening in the year when the spending occurs. For example, of the £2.1 billion spent in 2026/27, £0.21 billion is recovered that year. The remaining £1.91 billion is recovered in equal shares over 45 years, coinciding with the assets' lifetimes. As expected, cost recovery increases as more of the spending occurs, peaking in the last year of the investment spending. It then remains steady for approximately 40 years before tapering off. The entire cost recovery ends in 2075, 49 years after the start of spending, and thereafter, there are no further costs to recover.

3.2.2. Changes in electricity demand

The proposed investment spending during the RIIO-T3 price control period is motivated mainly by the need to service a projected increase in electricity demand over the subsequent years. The GB National Grid Electricity System Operator (NESO) publishes variations of their Future Energy Scenarios (FES) on an annual basis. SP Energy Networks' investment plans are linked to the 'Leading the Way' scenario of the 2023 FES (National Energy System Operator, 2023b),[5] and thus, we base our modelled demand projections on the same, specifically, projections of

[4] The estimation of the investment requirements has been conducted by SPEN, rather than the authors of this study, using their own specialised analytical methods. All, the RIIO-T3 Business Plan documents can be found at: https://www.spenergynetworks.co.uk/pages/riio_t3_docs.aspx.

[5] As with the investment estimates, the projected electricity demand changes have been calculated using the NESO analytical tools. The data used in this work can be accessed at: https://www.neso.energy/document/283061/download.

Table 1
Distribution of investment spending over the RIIO-T3 price control period.

Year	2026/27	2027/28	2028/29	2029/30	2030/31	Total
Allocated amount (£ billion, 2023 prices)	2.1	2.2	2.3	2.2	1.8	10.6
Annual share	19.94 %	20.32 %	21.28 %	21.08 %	17.37 %	
Annual share of network expansion	0.98 %	0.99 %	1.04 %	1.03 %	0.85 %	4.89 %
Accumulation of network expansion	0.98 %	1.97 %	3.01 %	4.04 %	4.89 %	

electricity demand therein.[6]

Given that the investment spending we consider here involves only part of the total GB and wider UK electricity demand served by SP Energy Networks, we scale the demand changes to reflect the size of the network expansion we consider. Specifically, we model 7.51 % of the total projected change in electricity demand, i.e., the share of the transmission network we consider here relative to the total capital of the UK electricity sector. Furthermore, because all the inputs in our model are in monetary values, we had to convert the projected demand change from physical units to monetary value. We do so by calculating the projected percentage change in demand relative to 2025, the assumed year 0 in our simulations, and then deriving the value changes from electricity-sector output in our SAM. Table 2 summarises the changes in electricity demand in our scenarios.

It is important to note that we only model the household demand for household quintiles in our model as described in (7). The additional, non-household, demand is modelled as an exogenous shock to electricity demand in line with (1). This decision is deliberate, as there is little information in FES on the distribution of the projected increase in electricity demand across the different UK sectors. Following this approach allows us to capture the price impacts of increased demand without introducing distortions driven by our assumptions about how demand will change across the different sectors. Finally, we model demand changes from 2027 onwards, as the 2026 investment will only lead to capital changes from 2027, while we do not model any demand changes beyond 2031, as these would require investments beyond the information available to us at this time.

3.2.3. *The scenarios modelled and sensitivity analyses*

Based on the information presented above, we consider two core scenarios:

- **Scenario 1**: Exogenous investment in the network expansion, along with the projected electricity demand increase and a 45-year cost recovery
- **Scenario 2**: Endogenous investment, where we allow the projected electricity demand to drive the electricity network response, including the additional capital required[7]

In this work, we conduct two separate sensitivity analyses. First, we explore the implications if only 50 % of the projected electricity demand materialises within the expected timeframe. This issue is relevant for both our core scenarios. Secondly, we consider a case with a sticky market electricity price, i.e., $Pelemc_t$ in (8), so that any gap between supply and demand is not reflected in the electricity price, and any changes in the electricity price are driven exclusively by the need to recover the cost of network expansion. We note that, for a large-scale investment programme such as the one we consider in this work, it would be reasonable to assume that recovering its costs would lead to higher electricity bills. We observe this bill increase in Scenario 2 (see Section 4.2), but not in Scenario 1 (see Section 4.1). Hence, conducting a sensitivity analysis where the competitive market price of electricity remains fixed is particularly important for our first core scenario. Therefore, the sensitivity scenarios are:

- **Scenario 3a**: As in Scenario 1, but with 50 % of the electricity demand increase
- **Scenario 3b**: As in Scenario 2, but with 50 % of the electricity demand increase
- **Scenario 4**: As in Scenario 1, but with a sticky electricity price

Table 2
Changes in electricity demand compared to the base year 2025 (all values in £ million, at 2023 prices).

Year	2027	2028	2029	2030	2031-onwards
Non-household demand	793.96	1,121.60	1,520.46	1,953.24	2,425.53
Lowest-income households HG1	−7.54	−4.25	0.97	7.92	17.46
Lower-income households HG2	−10.22	−5.76	1.31	10.74	23.66
Middle-income households HG3	−10.81	−6.09	1.39	11.36	25.02
Higher-income households HG4	−11.86	−6.68	1.52	12.45	27.44
Highest-income households HG5	−13.32	−7.51	1.71	13.99	30.82

4. Results and discussion

4.1. *Anticipatory investment at pace (central case)*

We initially focus our attention on the case of investment at pace, in line with the RIIO-T3 business plan submissions that all UK transmission owners must make to Ofgem. Historically, the concern regarding investment at pace has been that anticipatory investment in the electricity sector, beyond the observed network activity, could impose substantial costs on consumers, who are generally required to cover any investment spending via their energy bills. In the absence of confirmed increases in electricity demand, investing early in new capacity and incurring such costs has generally been regarded as risky, undesirable, and likely regressive (given the larger share of energy spending in total consumer spending among lower-income households). On the other hand, from a basic supply and demand perspective, creating excess capacity could introduce offsetting downward pressure on electricity prices and, thus, on bills.

See the results for Scenario 1 (Sc1) in Table 3, which reflect the outcomes of a positive investment shock in a constrained economic landscape, where the capacity created by that investment (here in the network element of electricity supply capacity) is ultimately fully utilised by the projected demand it was introduced to meet.

However, where we have anticipatory investment at pace, it is

[6] The evolution of demand in our scenarios is informed by the data in Table ES.02 of the 'Future Energy Scenarios 2023 Data Workbook'.

[7] In this scenario, the investment for all sectors, including Electricity, is determined by equation (3).

Table 3
Comparative economy-wide impacts of alternative network expansion scenarios (values in 2023 prices).

	Year	2030		Long-run	
	Scenario	Sc1	Sc2	Sc1	Sc2
Economy-wide results	**GDP (£million)**	1,044	122	1,999	1,548
	Employment (FTE)	7,447	−122	11,459	8,357
	Unemployment (% change)	−0.591 %	0.010 %	−0.909 %	−0.663 %
	Nominal wage - index to 1 (% change)	0.156 %	0.097 %	0.159 %	0.143 %
	Real wage - index to 1 (% change)	0.067 %	−0.001 %	0.103 %	0.075 %
	CPI - index to 1 (% change)	0.089 %	0.098 %	0.056 %	0.068 %
	Exports (£million)	−1,238	−1,034	−806	−877
	Imports (£million)	1,516	1,286	1,455	1,420
	Total household consumption (£million)	1,291	471	1,662	1,356
	Total investment (£million)	1,863	607	1,180	930
Electricity sector results	**Investment (£million)**	1,240	693	625	531
	Capital stock (% change)	4.041 %	1.370 %	4.891 %	4.159 %
	Rate of return to capital (% change)	−2.068 %	4.156 %	−1.407 %	0.067 %
	Output price/ electricity bill impact (% change)	−0.005 %	0.924 %	−0.279 %	0.044 %
Household results (per income quintile)	**Real disposable income_HG1 (£/household)**	22.64	9.35	27.36	22.81
	Real disposable income_HG2 (£/household)	30.98	9.15	40.85	32.67
	Real disposable income_HG3 (£/household)	43.77	14.73	56.95	46.10
	Real disposable income_HG4 (£/household)	57.95	17.64	77.82	62.27
	Real disposable income_HG5 (£/household)	78.53	34.41	98.08	81.89
	CPI_HG1 (% change)	0.088 %	0.106 %	0.051 %	0.066 %
	CPI_HG2 (% change)	0.088 %	0.103 %	0.052 %	0.066 %
	CPI_HG3 (% change)	0.089 %	0.097 %	0.055 %	0.067 %
	CPI_HG4 (% change)	0.090 %	0.095 %	0.057 %	0.068 %
	CPI_HG5 (% change)	0.091 %	0.091 %	0.060 %	0.069 %

plausible, as is the case here, that although the investment is appropriate to cover a longer-term projected increase in electricity demand, the capacity created is under-utilised until the projected demand fully transpires. Assuming that network operators remain committed to the capacity they have invested in (i.e., there is no disinvestment as the return to capital falls during periods of under-utilisation), this introduces downward pressures on the price of electricity industry output and on user bills.

Indeed, by the end of the price control and investment period, we see a net marginal reduction in the average electricity bills of 0.005 %. Within this, the recovery of the network expansion cost drives a gross increase in the electricity consumption price (as discussed in Section 3.1.4), which is regressive in nature. On the other hand, the excess capacity generated by the investment at pace drives a gross reduction in the output price of the electricity sector, noting that the exogenous nature of the investment means that the output price does not adjust to offset the reduction in the return to capital experienced by the electricity sector (see Table 3). The combined effect of the two drivers ultimately leads to the observed net reduction in electricity bills, which is mildly progressive in the CPI impacts felt by the average household within each income quintile. This reduction expands to an average of −0.12 % beyond the end of the price control period. Once cost recovery is complete, the downward price pressure from investing in electricity supply (here, network) capacity dominates, and Table 3 reports a sustained net reduction in average electricity bills of −0.279 %.

A key impact of this albeit small electricity bill reduction is to free up real disposable household income for spending on other things, where there is a positive (and progressive) gross impact on purchasing power, given that electricity is one of the main goods where households spend their disposable income, particularly in the lower income quintiles. On the other hand, the introduction of a relatively large investment activity into the supply-constrained UK economy means the CPI rises for all households, thereby constraining positive household consumption effects, but the impact remains marginally progressive.

However, the net impact is complex, given that households supplying capital and/or labour to the production process will benefit from increased returns to constrained factors of production, particularly in expanding activities (here concentrated in the electricity and construction industries), while losing out in sectors where activity levels are negatively affected. This employment and other income generation impact will be more important for higher-income households (who earn more from labour and/or capital), particularly when we assume the real value of government transfers to households (including benefits) is fixed.

Overall, the net impact reported in Table 3 is positive, with the real disposable income of households and, by extension, their consumption increasing by an average of £46.78 per household in 2030 and £60.21 per household per year in the long-run. While cost-price pressures triggered by the expansion of domestic electricity supply and construction activity do result in a net reduction in UK competitiveness and export production, the net impact on GDP is positive, with an uplift of £1.04 billion per annum in 2030 and almost doubling by 2050, which represents a new long-run equilibrium. See the Sc1 GDP and employment trajectories in Fig. 1. The underlying displacement of activity is reflected in the Sc1 sectoral employment impacts for 2030 and the long-run reported in Fig. 2.

It is important to note that, despite the net export losses triggered by price pressures, some sectors still benefit from lower electricity prices. For instance, manufacturing industries like 'Cement/lime/glass', 'Iron/steel' and 'Fabricated metal', where electricity is an important share of their production inputs, benefit in the long-run from reduced electricity prices, as reflected in their changes in export demand. In the absence of wage pressures, which we do not report here, export gains are even greater, highlighting the role of lower electricity prices in boosting the productivity of these sectors.

However, the key question is how important the specific features of the paced anticipatory investment case are in driving these economy-wide outcomes, and how relevant are the mildly progressive impacts of the energy bill?

If we considered the other extreme of an exogenous investment case and assumed there were no electricity network investments in anticipation of or in response to projected increases in electricity demand (which may not be technically feasible), a key outcome would be a significant increase in electricity prices and user bills. We do not report results for such an extreme scenario here, but note that test simulations

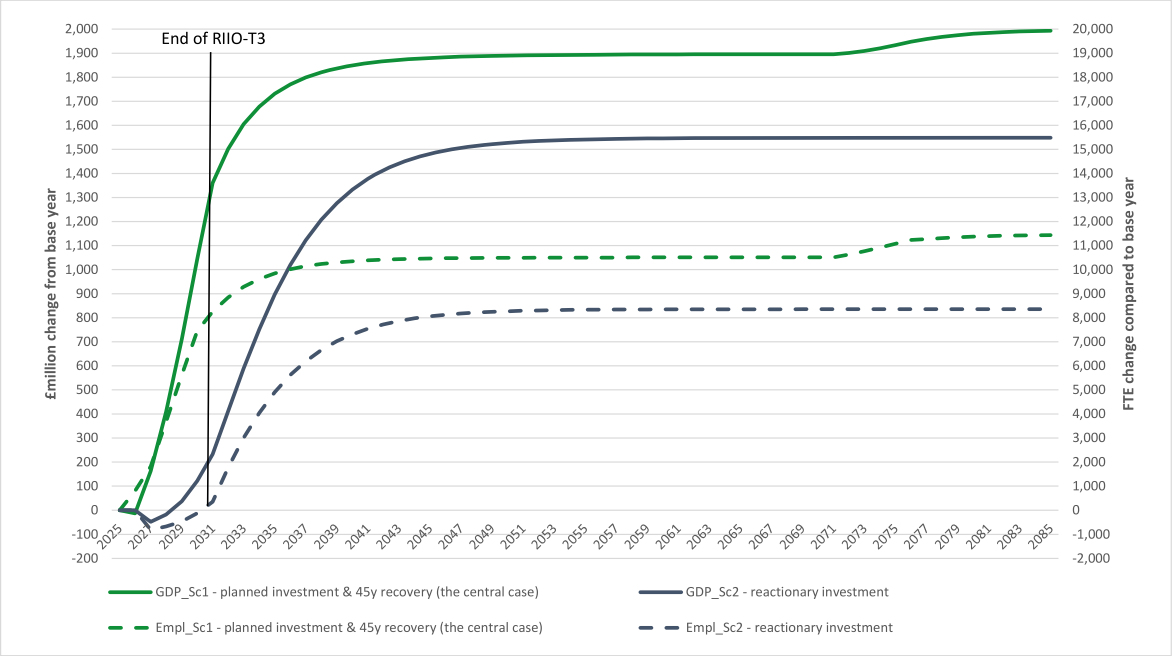

Fig. 1. UK GDP and employment trajectories for Sc1 - planned investment vs Sc2 - reactionary investment (all values in 2023 prices).

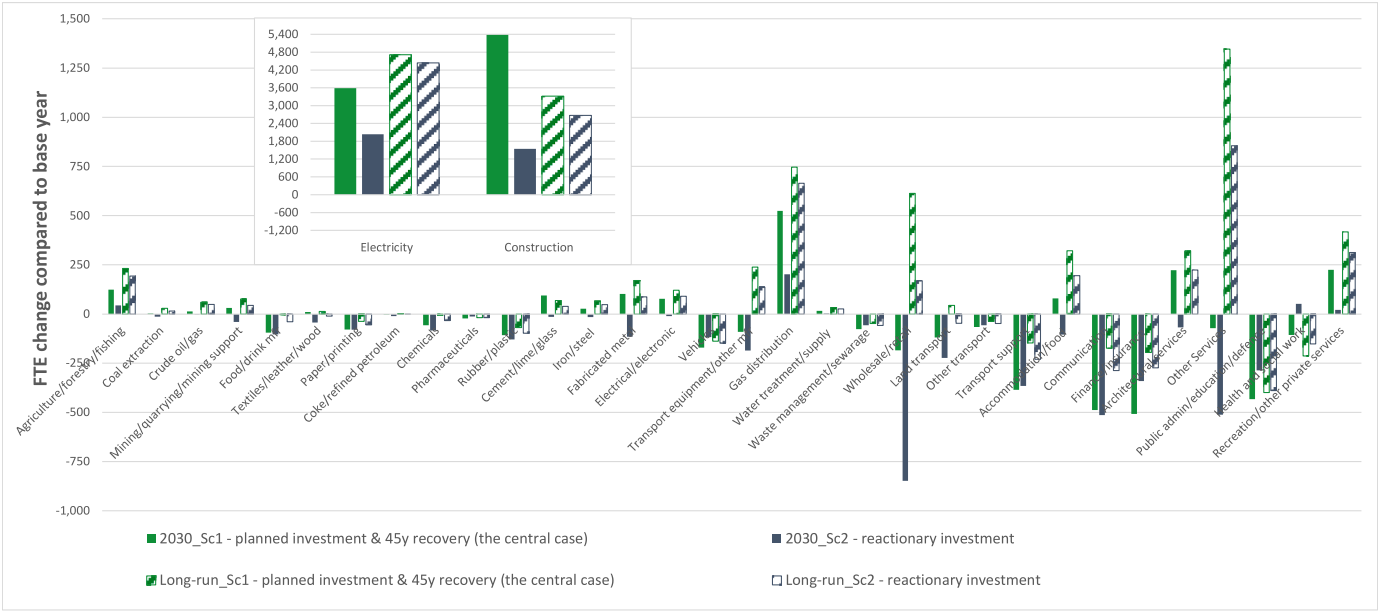

Fig. 2. Sectoral breakdown of employment changes due to alternative network expansion scenarios.

confirm such rigidity in electricity supply activity would likely trigger a highly regressive wider economy contraction in the context of substantial increases in demand and the resulting cost-price pressure. The crucial point is that the electricity bill impact is the key driver of outcomes in the case of no expansion in supply capacity. However, what if there is investment in the electricity network/supply capacity in response to increasing electricity demand, but it is purely reactionary, only once demand changes actually occur?

4.2. *Implementing a reactionary investment*

Sc2 represents a different kind of economic shock relative to Sc1. Now, instead of electricity network investment driving the net boost to the UK economy, the Sc2 results in Table 3 reflect the outcomes of the projected electricity demand shock fully transpiring and network investment responding, with the key driver being the return to capital in the electricity sector, which in turn drives the electricity price and bill effects. Now, with demand leading supply, the net electricity bill reduction observed in the Sc 1 results does not transpire. Indeed, it is not possible, where (as set out in Section 3.1.1) our treatment of investment involves the capital stock in any production sector gradually adjusting to the desired level, where this is only fully achieved after the demand, here for the electricity sector outputs, has effectively reached its long-run level for a number of years. Thus, in most timeframes, demand exceeds supply, putting upward pressure on the average electricity bill.

Besides bridging the gap between supply and demand, the long-run investment adjustment restores the return to capital of the electricity sector close to the original levels, easing the upward price pressures in

the electricity price that are further aggravated by the significant increase in the return to capital in previous periods. Some demand-driven price pressures are expected to persist in the long-run, as electricity demand is higher than in the base year.

Higher electricity bills imply that households' real disposable income gains are eroded relative to Sc1, thereby eroding the increase in household consumption. This erosion is further aggravated by wage pressures that continue to affect the competitiveness of UK sectors, now compounded by broader economy-wide pressures (see CPI), leading to greater employment losses in some sectors. In fact, as shown in Table 3, we observe net employment losses of −122 FTE jobs by the end of the price control period. Fig. 2 highlights that these employment losses are mainly observed in labour-intensive sectors such as 'Wholesale and Retail Trade', 'Communications' and the aggregated 'Other Services' sector.

Similarly to Sc1 outcomes, higher-income households still benefit more from the albeit now smaller scale expansion of the UK economy, primarily due to increased returns to capital in most sectors, which positively affect their income from capital ownership alongside generally higher wage income from employment. However, the crucial difference in Sc2 is that, in addition to real disposable income gains accruing more to higher income households, the absence of a net reduction in energy bills means that the CPI impacts of the network expansion become regressive throughout the transition to the new long-run equilibrium. This finding highlights the importance of the output price of the electricity sector in determining whether the impacts of the network expansion will be progressive or regressive. We focus on different ways that can influence the output price of electricity in our sensitivity analyses.

Ultimately, reduced household consumption, the smaller investment required to support the additional electricity demand, and the impacts of higher prices on UK exports lead to smaller GDP gains when we assume a reactionary investment. In fact, there are also some potential transitory GDP losses in the early stages of the investment period (see Fig. 1). Across all timeframes, a notable gap emerges in GDP and employment gains between Sc1 and Sc2, with Sc1 showing larger gains during the network expansion process, linked to lower investment requirements in Sc2.

Thus, our scenario simulation results show that investment at pace could lead to better economy-wide outcomes across all timeframes compared to a reactionary investment, partly fuelled by electricity bill reductions enabled by supply moving ahead of and anticipation of changes in demand, where this latter driver could also unlock outcomes that are at least not clearly regressive.

However, these results assume that electricity demand will increase as projected. There is an important challenge: if the demand does not materialise as projected, there is a risk that investment at pace will lead to stranded assets, for which the electricity users will still have to pay, and which could be avoided if investment simply reacts to demand.

4.3. Sensitivity analysis 1: The implications of a smaller increase in electricity demand

Our findings so far indicate that the electricity bill impact plays an important role in determining the economy-wide impact of the network expansion and whether the impacts will be progressive or regressive. One factor that influences the impact of the electricity bill is the additional electricity demand that investment in network expansion aims to serve. Table 4 presents the long-run results for scenarios Sc3a and Sc3b, now with only 50 % of the initially projected demand increase manifesting, compared to the results of Sc1 and Sc2 in Table 3.

The impacts of lower demand differ, both quantitatively and qualitatively, depending on the nature of the investment we consider. In the case of investment at pace (Sc1 and Sc3a), if only 50 % of projected demand materialises, this implies a much larger excess supply of electricity across all timeframes and into the long-run. This situation translates to greater gross negative pressures on the price of output in the electricity sector/user bills and, given the exogenous determination of the anticipatory investment (i.e., it is unchanging between Sc1 and Sc3a), this is associated with an even greater reduction in the return to capital for the electricity sector. This result reflects a stranded asset situation in which additional network assets are created, not fully utilised, but cannot be disinvested.

Such a situation (an unsustainable picture for the electricity industry) occurs despite the economy-wide results suggesting a more positive picture where the positive impacts of net reductions in energy

Table 4
Comparative long-run economy-wide impacts of alternative network expansion scenarios and levels of additional electricity demand (values in 2023 prices).

	Scenario	Sc1	Sc3a	Sc2	Sc3b
Economy-wide results	**GDP (£million)**	1,999	2,502	1,548	775
	Employment (FTE)	11,459	16,082	8,357	4,185
	Unemployment (% change)	−0.909 %	−1.276 %	−0.663 %	−0.332 %
	Nominal wage - index to 1 (% change)	0.159 %	0.135 %	0.143 %	0.071 %
	Real wage - index to 1 (% change)	0.103 %	0.145 %	0.075 %	0.038 %
	CPI - index to 1 (% change)	0.056 %	−0.010 %	0.068 %	0.034 %
	Exports (£million)	−806	−168	−877	−439
	Imports (£million)	1,455	849	1,420	710
	Total household consumption (£million)	1,662	1,855	1,356	678
	Total investment (£million)	1,180	1,428	930	465
Electricity sector results	**Investment (£million)**	625	625	531	266
	Capital stock (% change)	4.891 %	4.891 %	4.159 %	2.080 %
	Rate of return to capital (% change)	−1.407 %	−5.542 %	0.067 %	0.034 %
	Output price/ electricity bill impact (% change)	−0.279 %	−1.212 %	0.044 %	0.022 %
Household results (per income quintile)	**Real disposable income_HG1 (£/household)**	27.36	28.98	22.81	11.41
	Real disposable income_HG2 (£/household)	40.85	47.82	32.67	16.34
	Real disposable income_HG3 (£/household)	56.95	64.87	46.10	23.05
	Real disposable income_HG4 (£/household)	77.82	90.98	62.27	31.14
	Real disposable income_HG5 (£/household)	98.08	103.45	81.89	40.95
	CPI_HG1 (% change)	0.051 %	−0.025 %	0.066 %	0.033 %
	CPI_HG2 (% change)	0.052 %	−0.020 %	0.066 %	0.033 %
	CPI_HG3 (% change)	0.055 %	−0.011 %	0.067 %	0.034 %
	CPI_HG4 (% change)	0.057 %	−0.006 %	0.068 %	0.034 %
	CPI_HG5 (% change)	0.060 %	0.002 %	0.069 %	0.034 %

bills (with the excess supply driven reductions more than offsetting the impact of recovery of the investment costs in unused capacity) completely offset any value-added and employment losses associated with the smaller electricity consumption.

On the other hand, when we assume a reactionary investment (now comparing Sc2 and Sc3b), the smaller demand volume results in less network investment and smaller economy-wide gains across all time-frames (see Fig. 3). The more limited gains in value-added and employment associated with smaller electricity consumption and smaller investment needs to support the additional demand are sufficient to completely offset any observed benefits from reduced electricity bill increases (see Table 4).

It is important to note that, regardless of the investment approach, reduced additional electricity demand leads to progressive impacts on households, as excess capacity limits energy bill pressure (i.e., the cost is borne by the owners of capital, whose rate of return falls). However, the investment approach does shape the likely regressive or progressive nature of the impacts, with anticipatory investment at pace leading to more clearly progressive impacts for households.

4.4. *Sensitivity analysis 2: what if the marginal price of electricity does not change?*

A key determinant of the central case scenario (Sc1) potential outcomes above is what happens to the marginal price of electricity industry output and, thus, the size of user bills. Specifically, the gap between supply and demand drives gross downward pressures to electricity prices when we consider anticipatory investment at pace (Sc1), with this driver becoming more important if projected electricity demand does not fully materialise (Sc3a). A key question is how different the outcomes, and specifically the net wider economy benefits, of anticipatory investment would be if there were no energy price/bill adjustment in response to supply-demand differentials to mitigate the recovery of investment costs through user bills. We consider this in scenario Sc4, the results of which are reported in Table 5, compared with those of Sc1.

Because the marginal electricity price does not adjust to reflect excess supply or demand at any point in time, the only factor directly affecting user bills is the mark-up introduced to recover the cost of the network upgrade, driving upward pressures on energy bills for as long as the recovery period lasts. Thus, user bills rise for the entire cost recovery period (to 2075) before returning to base-year levels (given the absence of any other simulated disturbances).

A key outcome is that the absence of any downward pressure on electricity bills combines with other price pressures emerging in the constrained economic landscape (here mainly due to worker shortages) to almost entirely offset any real disposable income boost to households associated with increased employment, and there is a marked erosion of household consumption benefits (where the CPI rises). Moreover, in the absence of any downward electricity price adjustments as electricity supply moves ahead of demand, the progressive nature of the household impacts in the core anticipatory investment case is reversed. For as long as the cost recovery period lasts, the network expansion affects different household income groups in a regressive manner.

At the economy-wide level, primarily due to smaller household consumption gains, a fixed variable component of the electricity price erodes the potential macroeconomic benefits from expanding the transmission network. Despite the absence of investment recovery in electricity bills, the gap in GDP and employment gains between Sc1 and Sc4 widens as the economy moves towards the long-run equilibrium, reflecting the importance of household outcomes in driving broader economic benefits. Crucially, the economy-wide gains in Sc4 are eroded compared to Sc1 to an extent that the economy-wide gains in Sc2 eventually become greater shortly after the price control period, in 2033, and into the long-run (see Fig. 4).

This brings forward an important consideration for policymakers, the regulator (responsible for delivering on the statutory Growth Duty in the UK), and the industry: there must be flexibility in electricity prices as the electricity network expands if wider economy gains are to be maximised and consumer costs minimised. Crucially, the economic benefits of early anticipatory investment could be largely negated, and outcomes for households become regressive if supplier prices do not adjust to reflect capacity conditions.

5. Conclusions

In this paper, we explore the potential economy-wide implications of expanding the electricity transmission network to meet projected

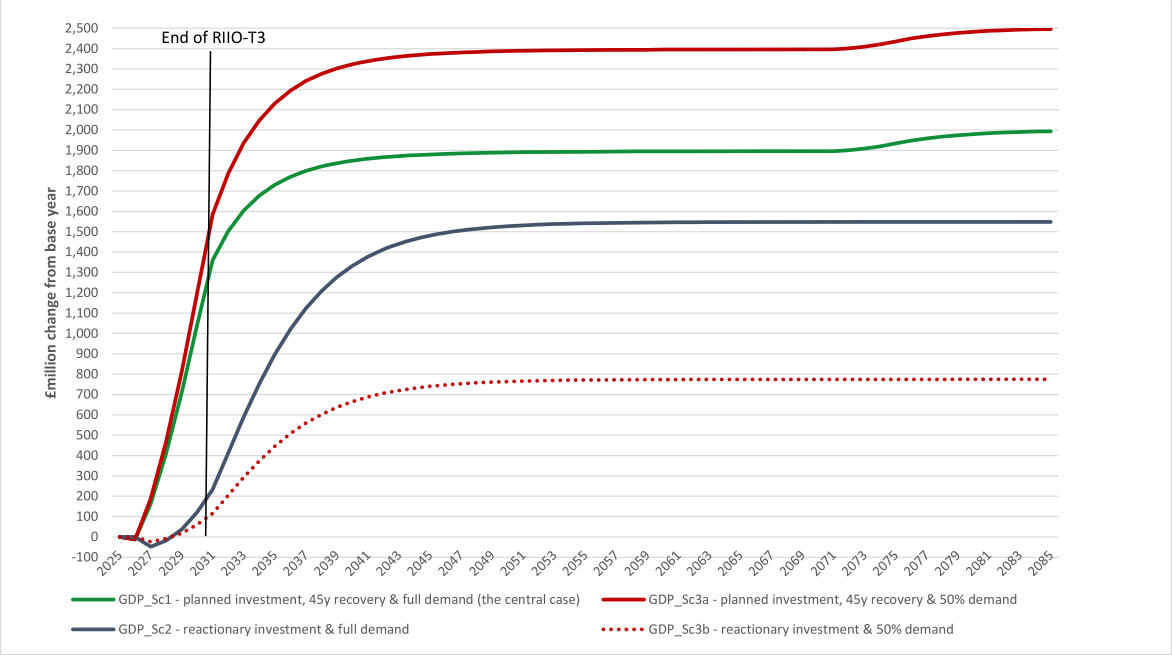

Fig. 3. UK GDP trajectories for Sc1 - planned investment vs Sc2 - reactionary investment and their sensitivity analysis cases Sc3a and Sc3b (all values in 2023 prices).

Table 5
Comparative economy-wide impacts of alternative electricity price scenarios (values in 2023 prices).

	Year	2030		Long-run	
	Scenario	Sc1	Sc4	Sc1	Sc4
Economy-wide results	**GDP (£million)**	1,044	749	1,999	1,157
	Employment (FTE)	7,447	2,521	11,459	3,543
	Unemployment (% change)	−0.591 %	−0.200 %	−0.909 %	−0.281 %
	Nominal wage - index to 1 (% change)	0.156 %	0.070 %	0.159 %	0.058 %
	Real wage - index to 1 (% change)	0.067 %	0.023 %	0.103 %	0.032 %
	CPI - index to 1 (% change)	0.089 %	0.047 %	0.056 %	0.027 %
	Exports (£million)	−1,238	−614	−806	−349
	Imports (£million)	1,516	676	1,455	572
	Total household consumption (£million)	1,291	128	1,662	198
	Total investment (£million)	1,863	1,403	1,180	790
Electricity sector results	**Investment (£million)**	1,240	1,240	625	625
	Capital stock (% change)	4.041 %	4.041 %	4.891 %	4.891 %
	Rate of return to capital (% change)	−2.068 %	−7.924 %	−1.407 %	−8.591 %
	Output price/ electricity bill impact (% change)	−0.005 %	0.269 %	−0.279 %	0.000 %
Household results (per income quintile)	**Real disposable income_HG1 (£/household)**	22.64	0.24	27.36	0.84
	Real disposable income_HG2 (£/household)	30.98	4.06	40.85	6.20
	Real disposable income_HG3 (£/household)	43.77	4.78	56.95	7.43
	Real disposable income_HG4 (£/household)	57.95	8.53	77.82	12.92
	Real disposable income_HG5 (£/household)	78.53	5.60	98.08	8.44
	CPI_HG1 (% change)	0.088 %	0.048 %	0.051 %	0.026 %
	CPI_HG2 (% change)	0.088 %	0.048 %	0.052 %	0.026 %
	CPI_HG3 (% change)	0.089 %	0.047 %	0.055 %	0.026 %
	CPI_HG4 (% change)	0.090 %	0.047 %	0.057 %	0.027 %
	CPI_HG5 (% change)	0.091 %	0.046 %	0.060 %	0.027 %

increases in electricity demand. Our key focus is whether there are likely to be differences in the wider economy and household outcomes between early planned (anticipatory) investment and a reactionary approach to adjusting network capacity. These analyses are enabled by our dynamic CGE modelling approach, which captures labour market and cross-sectoral price pressures, moving beyond typical quantitative analyses in this field that often rely on partial-equilibrium or cost-benefit analyses. This holistic reflection on the economy-wide impacts of investments in the electricity network makes our findings relevant to policy questions, such as those associated with Ofgem's statutory growth duty.[8]

One fundamental finding is that the combination of investing in and operating an expanded electricity transmission network will generally drive sustained economy-wide gains, regardless of the timing of the investment. However, the specific nature and extent of wider economy net benefits do depend on the 'when and how'.

Our central finding is that early, planned investment at pace has the potential to boost the GDP and employment gains while ensuring that any price impacts are progressively distributed across households and locking in real income and spending gains, even in the presence of increased CPI pressure where labour market constraints bite.

However, we also find that the strength and presence of all such positive impacts depend crucially on whether the marginal price of output in the electricity industry adjusts with capacity conditions. In our central scenario, investment at pace could put downward pressure on electricity prices and, by extension, all energy bills. This is not a common observation across all scenarios, though, with the level of the electricity price changes playing a key role in determining the economy-wide outcomes. This underpins the key message for policymakers, regulators, and industry actors that sustainable economic growth outcomes, such as those required under Ofgem's statutory Growth Duty in the UK, depend on flexibility in electricity price determination.

Going forward, several ways to improve the applied analyses of the type reported here exist. First, one challenge in conducting the work reported here is that, as in many other countries, the official UK input-output tables used to build the structural database of our CGE model report only a single, vertically aggregated electricity sector. Future work would ideally be conducted using a dataset where the different components of the electricity industry (generation, transmission, distribution, retail) are separately identified and can be individually shocked.

Second, here we have focused exclusively on one of the UK transmission network operators. Subsequent work should incorporate the investment activity of all three UK transmission operators (TOs), not least because a greater (combined) level of investment and electricity demand will cause the UK labour market and other constraints to bite further. Third, considering electricity supply activity more holistically will require analyses to extend to the distribution network, where pricing and investment cost recovery structures will differ from those in the transmission case. This work could be conducted similarly to this work, in collaboration with the UK's distribution network operators, or by employing existing analytical methods that explore the potential need for investment in distribution networks (e.g., European Commission: Directorate-General for Energy, 2022; Giannelos et al., 2024).

Nonetheless, this paper has provided an important first step in enabling decision-making in the electricity industry investment to take into account sustainable economic growth processes. Finally, this work has focused mainly on the residential sector, but we have noted that electricity prices may also affect production sectors. It is therefore important to conduct dedicated analyses of how investment in the electricity sector may affect the UK economy's overall competitiveness, as well as competitiveness at the sectoral level.

CRediT authorship contribution statement

Antonios Katris: Writing – original draft, Visualization, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Anas Karkoutli:** Writing – original draft, Visualization, Methodology, Data curation.

[8] It is important to be emphasised that our analyses aim to support a more in-depth understanding of the nature and the magnitude of the potential economy-wide impacts, triggered by the investment in the electricity transmission network. There was never any intention though for our findings to be a forecasting exercise, and should therefore not be treated as one.

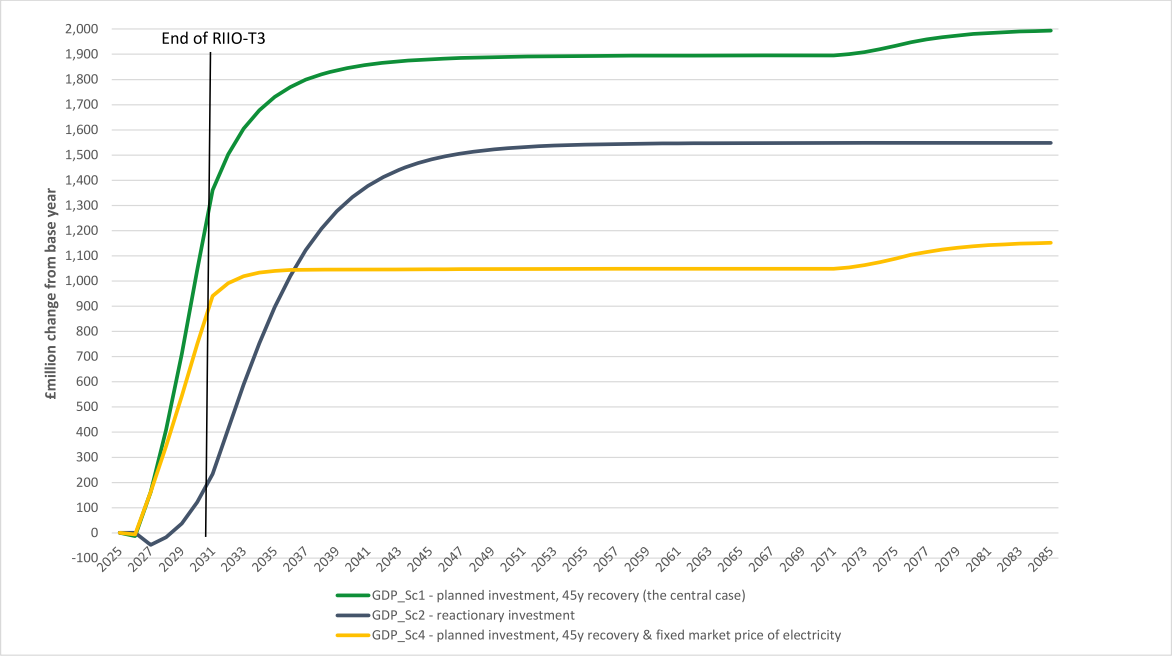

Fig. 4. UK GDP trajectories for Sc1 - planned investment vs Sc2 - reactionary investment and the sensitivity analysis Sc4 (all values in 2023 prices).

Karen Turner: Writing – original draft, Supervision, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

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Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Antonios Katris reports financial support was provided by Scottish Power Energy Networks. Karen Turner reports financial support was provided by UK Research and Innovation. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Listing of variables and parameters

Variables

Variable name	Variable description
$X_{i,t}$	Total output
$M_{i,t}$	Total import
$VV_{i,j,t}$	Total intermediate inputs from i to sector j
$QH_{i,h,t}$	Total households' consumption of sector i output
$QV_{i,t}$	Total investment by sector of origin i
$QG_{i,t}$	Total government expenditure to sector i
$E_{i,t}$	Total export
$EXO_{i,t}$	Exogenous demand for sector i output
$INTele_{j,t}$	Intermediate demand for electricity by sector j
PE_t	Price of composite energy good
$Pele_t$	Price of electricity faced by all users

(*continued on next page*)

(*continued*)

Variable name	Variable description
$INTEN_{j,t}$	Total intermediate energy demand by sector j
$I_{j,t}$	Investment by sector of destination j
$KS^{*}_{i,t}$	Desired capital stock
$KS_{i,t}$	Actual capital stock
$I0_{ele}$	Initial investment in the electricity sector (in year 0)
$ExoI_{ele,t}$	Exogenous investment shock to the electricity sector
w_R	Real wage rate
u_t	Unemployment rate
$ELE_{h,t}$	Household consumption of Electricity
CPI	Consumer price index
$C_{h,t}$	Aggregated household consumption
$Pele_t$	Price of electricity faced by all users
$EXOQH_{h,t}$	Exogenous demand shock to household electricity demand
$Pelemc_t$	Electricity price in a perfectly competitive market
θ_t	Mark-up to the market price of electricity
mp_t	Marginal profit of electricity firms
$\overline{NTW_t}$	Total revenue from electricity sales

Parameters and elasticities

Parameter/elasticity name	Parameter/elasticity description	Default value (where applicable)
A^E	Input-output coefficient for energy used by sector j	Estimated at calibration
δ_j^{INTele}	Share parameter in the CES function for intermediate goods	Estimated at calibration
ρ_j^E	Elasticity of substitution between energy and Non-energy goods in production	0.3
ν	Adjustment coefficient of capital stock	0.5
δ	Capital depreciation rate (fixed)	0.15
ω	Parameter calibrated to the steady state	Estimated at calibration
ε	Elasticity of wages to the unemployment rate	0.113
δ_h^C	Share parameter in the CES function for household consumption	Estimated at calibration
ρ^C	Elasticity of substitution between residential energy and other goods and services	0.61

Appendix B. Schematic representation of UKENVI

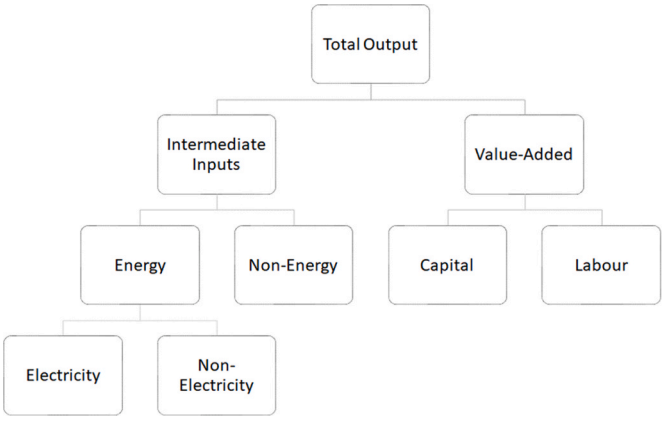

Fig. B.1. Representative CES production structure

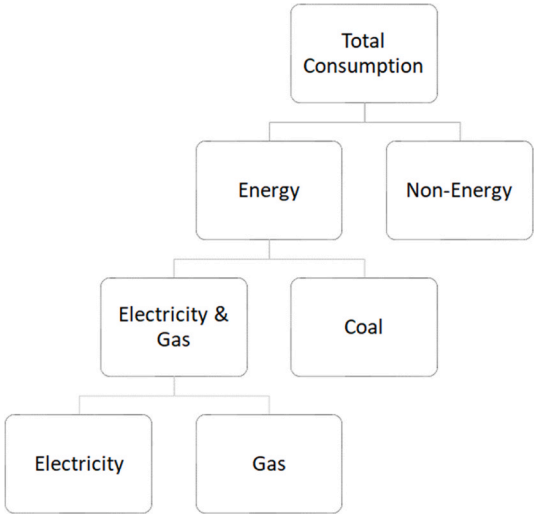

Fig. B.2. Representative CES consumption structure

Table B.1
Sectoral aggregation in the CGE model and link to SIC2007 codes

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

Data availability

The specific information used to develop the scenarios of this work are described in Section 3.2

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