Who Ultimately Pays for and Who Gains from the Electricity Network Upgrade for Electric Vehicles (EVs)?

by

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Abstract

This paper investigates the question of who ultimately pays and who gains from upgrading the power network to facilitate the roll out of EVs required, for example, under ambitious targets set by the Scottish and UK Governments. We apply a multi-sector computable general equilibrium (CGE) model for the UK economy to consider network upgrade and EV penetration scenarios for the period to 2030. We investigate the year-by-year economy-wide impacts of a scenario involving a partly centralised/smart EV charging system. We find that all UK households do suffer net negative impacts on real income, due to a combination of how the time-limited large-scale investment in the presence of capacity constraints impacts the price level in general and the fact that the costs are passed on to electricity consumers through higher bills. But the lowest income households – the group of greatest concern to policymakers – are impacted least and initially enjoy small net gains under some scenarios. The EV uptake delivers sufficient gains to deliver sustained expansion in GDP and employment across the economy. The key driver is a greater reliance on UK supply chains with the shift away from more import-intensive petrol and diesel fuelled vehicles towards electric ones.

Keywords: Electric Vehicles; Electricity Network; Computable General Equilibrium; domestic supply chains

JEL codes: L62 C68, Q43

Highlights:

- Exploiting domestic (UK) capacity and supply chains in fuelling of electric vehicles

- Shift to EVs can unlock, sustain and increase value in different parts of the economy

- Technology and cost considerations need to be set in context of economy-wide benefits

- EVs and other low carbon initiatives can deliver economic/industry policy outcomes

1.   Introduction

The UK and Scottish Governments have set ambitious targets for the roll-out of electric vehicles (EVs) by 2040 and 2032 (DEFRA 2017; Scottish Government (2017). These have been driven by the global recognition that EVs are a viable alternative to traditional fossil fuels vehicles and a key low carbon solution and technology for supporting the transition to the decarbonisation of transportation (European Commission 2014, IEA, 2017). Moreover, with the Paris Declaration on Electro-mobility and climate change aiming to increase electro-mobility to levels compatible with a less than 2°C pathways (United Nations, 2015), advancing electrification of transport is a stated priority for most countries. Electric Vehicles Initiative (EVI) member countries have taken renowned lead in this regard/respect. For instance, Norway set national targets of new vehicles to emit on average 85g CO_2/km by 2020 (Norway Government, 2014).Germany plans to roll-out at least 1million electric and plug-in hybrid vehicles by 2020 as declared in the national electro mobility development plan (German Federal Government, 2009).In the UK, efforts to further shift demand away from vehicles fuelled with petrol and diesel, the government has set a target of at least 50% of new vehicles to be ultra-low emission by 2030 in the recently launched 'Road to Zero Strategy (HM Government, 2018; Office for Low Emission Vehicles, 2018).

However, if the EV roll-out is to play its intended role in supporting national priority of reduction in greenhouse gas (GHG) emissions, it must gain support from a broad stakeholder policy community. In the paper we argue that a crucial element of this is demonstrating that the EV roll-out can contribute to unlocking, sustaining and increasing value in different parts of the economy. Policy attention in the UK has been directed in this way, but to date with focus mainly on the wider economy returns of locating the manufacture of vehicles and batteries 'at home'. Our proposition is that a more straightforward source of wider economy value will result from EVs being fuelled by the domestic electricity industry, which, certainly

in the UK, has a very strong domestic supply chain. We have previously argued this in a simpler economy-wide input-output (IO) multiplier framework (Turner et al., 2018a). Here we extend using multi-sector economy-wide computable general equilibrium (CGE) analysis to consider a fuller range of investment activities and market responses, which drive a range of distributional effects through income and price effects.

Like any transformative low carbon solution and technology, EVs presents a variety of challenges for the vehicles industry, fuel station operators, electricity network and the government. In particular, the EVs roll-out will have profound impact on the electricity system that will require upgrade to the electricity network itself, which will carry significant costs that are ultimately paid by consumers. Here we consider how consumers may be impacted both through energy bills and the costs of other goods and services (where electricity prices impact production costs). In the first instance, we investigate how the large-scale upfront but time-limited investment in electricity network infrastructure to support the EV-roll out could cause price increases and negative wider impacts across a constrained economy, where particular policy concern may lie with impacts on low income households (Ofgem, 2018). But our second question is the extent to which benefits triggered by the shift to domestically fuelled (and increasingly more efficient) EVs may offset this and deliver net wider economy gains, albeit with further distributional impacts (e.g. on petrol/diesel suppliers).

The remainder of the paper is organised as follows. Section 2 provides a synopsis of the existing and emerging discourse and debate around EV roll-out. In Section 3 we set out the core principles adopted in investigating the question of who pays and who benefits from the upgrade of the UK electricity network infrastructure and associated EV roll-out. Section 4 then details the CGE model specification and characteristics. It includes description of the UK dataset on which the model is calibrated, and the simulation strategy adopted, which

involves drawing on results of scenario analysis in an energy system (UK TIMES) model to inform on EV uptake, investment requirements and gains in vehicle efficiency. Section 5 presents and discusses the results. Finally, in Section 6 we offer our conclusions and thoughts on policy implications and future research needs.

2. Background to questions around EVs in the literature

Several studies have applied various models to estimate the implication and impacts of the roll-out of EVs. Some have largely focussed on the factors promoting and driving the shift to EVs, charging infrastructure requirements, and demand and/or consumer choice and behaviour of switching to alternative fuel vehicles (Jacobson and Delucchi, 2011; Budischak et al.,2013; Noel et al., 2017).

Other studies assess the potential economic cost and benefits of the roll-out and potential market penetration of EVs (Noel et al, 2018; Truong and Hesher, 2012; Schmelzer and Miess M., 2015). Studies considering consumer preferences and attitudes to the purchases of EVs have used survey and experimental choice methods to assess consumers perspectives and reactions on willingness to switch and pay for EVs, and their charging preferences (i.e. at home or at more centralised locations) (Dagsvik et.al. 2002; Glerum et al., 2011; Green et al.,2014; Noel et. al., 2012). Fernandez et al. (2011) focus on the impacts of different levels of plug in EVs penetration on distribution network investment, evaluation of network reinforcement and incremental energy losses. Lopes et al. (2011) evaluates the integration of EVs in the electric system and the grid control architecture and mechanism required. Another strand of the literature focus on the environment impact and technical progress associated with EVs (Helmers, 2010; Cames and Helmers, 2013; Degraeuwe et al., 2016)

Some authors highlight the need for active government support to incentivise and accelerate large-scale transition to EVs. These studies focus on using a combination of new and possibly innovative policy interventions and instruments, generally taxation and subsidies (e.g. Trans

et al., 2012; Lopez-Behar et al., 2019). On the other hand, there may be a gap in the literature in this regard, given the attention that policymakers and regulators have been giving to both developing and implementing mechanisms that protect consumers against higher electricity bills (which in turn impacts income and spending) *and* different charging regimes and infrastructure (Ofgem, 2018). Due to differences in electricity mix and national strategy the regulatory framework in other countries go beyond consumer protection to focus on wide economic protection in terms of maintaining jobs, export as well as protecting national wealth and growth (FMEEA, 2018)

In terms of methodological approaches, most existing EV studies employ bottom up models (e.g. optimization, statistical methods and simulation models) to consider the potential economic and technological implications of EV uptake (Gnann and Plotz 2015). These type of modelling frameworks are frequently used to analyse the impacts of integrating EVs with the electricity system/network, grid control design, type of charging infrastructure and vehicle efficiency to support EVs uptake and market penetration (see for example Dagsvik et al., 2002; Glerum et. Al., 2011; Link et al., 2012; Truong and Hesher, 2012). This is important as bottom up models and methods have a key role to play in developing wider evidence base to enable a detailed understanding the potential impacts of what are expected to be large-scale shifts towards electric vehicles in many countries. On the other hand, bottom up approaches are more limited in terms of insights on a fuller range of indirect and economy-wide benefits that are of concern to the wider policy stakeholder community (Turner et al. 2018a).

There are a number of studies that employ top down models in investigating issues around EVs roll-out (see, for example, Figus et al., 2018, Hirte and Tscharaktschiew, 2013; Li et al., 2017). In many of these studies, there is a common consensus that the roll-out of EVs will have both positive and negative impacts on both the wider economy and vehicle users

(Carlsson and Johansson-Stenman, 2003; Lemoine et al., 2008; Villar et al., 2013). Some of the positives impacts include; reducing vehicle operating cost, support to national and global CO_2 emission reduction objectives and improved air quality, stability and sustainable of the electricity system (Noel and McCormack, 2014). On the other hand, the market barriers and disadvantages include; high prices, short drive ranges, long recharging times, and an insufficient recharging infrastructure (Berkeley et al., 2018; O'Neil et al., 2019; Steinhilber et al., 2013; Vassileva and Campillo 2017).

In this paper we argue that to accurately evaluating the wider economy and individual consumer impacts (both cost and benefits) of the shift from petrol/diesel cars to EVs requires focussing in the first instance on the core issue of who ultimately pays for the upgrade and improvement of the electricity network infrastructure electricity network infrastructure.

2. How do we answer/address the question of 'who pays', and 'who gains'?

We begin by looking at how households and commercial consumers respond to the changes in costs of using an upgraded electricity system, and how this impacts prices and incomes across the UK economy. The distribution of the benefits of switching to EVs may shift over time. The new transport services[1] enabled by electricity network upgrades may not be enjoyed by many current system users, e.g. people who are not in the first wave of EV users. Crucially, we adopt four underpinning principles in analysing 'who ultimately pays' for the network upgrade required for EVs:

1. To fund the necessary investment, all costs are passed on to all current consumers through their bills. The cost can be recovered over a relatively long (multi-year) time period. Although they may ultimately be recovered more directly from EV users as uptake increases, we assume that recovery of the total investment costs is spread

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[1] Potentially with gradually reducing transport running costs as the efficiency of EVs increases, both relative to petrol/diesel in monetary cost per mile/km driven, and in absolute terms.

evenly over the lifetime of the assets created by the investment and reclaimed through electricity bills.

2. Commercial customers are likely to pass on their increased costs though their own output prices. Ultimately this will ripple through to domestic consumers in prices of other goods and services. Where firms export their output, the impact on UK households may be less direct, through the employment and income effects of any loss in competitiveness.

3. Where capacity constraints exist across the economy, the process of upgrading the UK electricity network infrastructure through large scale investment could trigger further price increases and negative wider economy impacts as the sectors involved draw in additional (but scarce) labour and capital resources. This will be exacerbated where forward-looking producers anticipate the conclusion of a time limited spending programme, particularly where large-scale spending is concentrated within a relatively short timeframe. In the applied case considered here, direct investment spending within the UK is focussed in the Construction sector, with other investment spending (equipment needs) made overseas. Thus, any disruption – and gains – are associated with a domestic investment spend that is lower than what has to be paid back by consumers through higher bills.

4. On the other hand, the uptake of EVs could trigger a stream of benefits. Based on the findings of our previous work (Turner et al., 2018a), we hypothesise that in the UK case a key source of benefits is likely to be economic expansion triggered by a shift in demand away from petrol/diesel (which has an import-intensive supply chain) and towards electricity in fuelling vehicles. Our previous work demonstrated that increased reliance on the strong domestic supply chain of the UK electricity sector may constitute a more straightforward source of wider economic gain than the

manufacture of electric vehicles and batteries. Moreover, where EVs are more efficient, in terms of the cost per mile driven, this may further trigger a demand-driven stimulus as real incomes rise and purchasing power is freed up for spending on other goods and services.

These basic principles are subject to practical complexity, particularly in terms of the timeframe over which the required network investment is carried out relative to the timing of the expected realisation of benefits through the EVs uptake.

First, as noted above, if we assume that producers are forward looking[2], in that they will recognise and anticipate when any large-scale investment is time limited to meet a particular requirement, this will influence both sectoral and market responses to that investment. Any major demand shock to the economy puts pressure on resources and prices. But if this is concentrated in a short timeframe (i.e. the investment boost is large but does not last for long), the impact can be more disruptive as resources are first drawn away then released again, with the latter potentially triggering negative net impacts at sectoral and economy-wide levels. Where producers anticipate this, they will be less willing to reallocate resources, which will dampen the expansionary process while also pushing up prices.

In the context of the UK electricity network investment required to support the projected EV rollout to 2030, the potential for this type of 'crowding out' raises questions as to how the investment required should spread in the period leading up to that time. On the one hand, the industry Regulator (Ofgem) may be cautious about creating new capacity too far ahead of the projected requirement (in case that does not materialise, and/or it impacts the efficiency with which existing capacity is used). On the other, particularly if constraints on labour and/or capital accumulation relax over time, the disruptive impacts of the network investment on the

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[2] The impact of the reaction and response of forward-looking producers to investment decisions has been widely discussed in literature. The assumption of forward-looking consumers is also a key question of specification in the type CGE modelling applied later in this paper (see Lecca et al., 2013).

wider economy are likely to be lessened if the spending and upgrade activity are spread over a longer timeframe in the lead up to 2030.

This leads us to a second point. By 2030 the expected UK EV penetration is only anticipated to be 20% (Calvillo and Turner, 2019; National Grid, 2018). It may then be argued that effective planning for a mass roll-out of EVs actually requires a continuous investment to meet desired penetration levels. However, there are questions as to how this would be planned for in practice. In the UK, network investment decisions are made on the basis of 5-year (previously 8-year) blocks which are referred to as 'price control' periods (Pearson and Watson, 2012; SPEN, 2018) and set in the context of initial delivery of outcomes/benefits within the same block of time. A further complication is that supporting the EV uptake is not the only demand on the UK electricity network: investment may spread across different price control periods in order to consider wide electrification programmes and actions/options.

These points combined provide an interesting motivation to focus on investigating the net costs and benefits of the roll-out of EVs to 2030 in the UK context, where electricity network investment plans are set in the context of ''price control periods' set by the UK Regulator, Ofgem, where costs and benefits are considered within 5-year blocks. To consider the case of a 'just in' time scenario (to meet increase demand), we consider network investment to meet projected 20% EV penetration by 2030 first in terms of spending and upgrade activity spread over 3 years (2027-2029, a single price control period), then over 12 years (2021-2032, cutting across more than one price control period). In doing so we consider three research questions, which reflect policy concerns in the UK:

i. How are the costs of electricity network investment and payback alone likely to impact low income households?

ii. How do network investment and the EV roll-out combine to impact the wider economy adjustment?

iii. What sectors of the economy gain the most and which lose out over different time frames?

In the analysis we do not extend to consider a wider set of questions, such as how tax revenues from fuelling vehicles may be impacted by a switch to electric fuelling. This is largely because no specific scenarios have been identified in UK policy or industry communities. We do flag this as a crucial focus for future research in Section 6. Our next step, in Section 4, is to set out the modelling approach used to consider the issues and questions set out here.

4. Method

Using the UK-ENVI CGE model previously applied in Figus et al. (2017) to consider the impact of energy efficiency programmes on household income and the wider economy, we simulate the impact of an investment spend on upgrading the electricity network on electricity consumer and the economy. In the context of EV penetration and improvement in efficiency, we draw on a variant of UK-ENVI, developed in Figus et al. (2018) that focused on modelling the impact of technical change on private transportation and improvement in vehicle efficiency. Both variants of the model are calibrated on a 2010 SAM for the UK (most recent year for which appropriate data are available). However, there are key differences and changes in the structure of the model that relates to the specification of increasing investment demand in the current paper. In the following sections we outline the main features of the model, focussing particularly on the structure of household consumption, production and investment.

4.1 What we need to simulate?

In the first instance, we focus on the investment stage. In particular, the level of investment for network upgrade to support the roll-out of EVs. There are three main elements to the investment stage:

1) The total value of the investment to be paid back via bills

2) How much of the investment spending is targeted within the UK

3) How the investment is spread over time periods modelled

To consider what might be the total value of investment, we have considered a number of scenarios around the extent to which the EV charging is smart and/or centralised. Our core focus is a mixed scenario that includes some extent of centralised and smart charging and for which a total investment value of £2.7billion needed by 2030. We assume that this is either made 'just in time' to meet 2030 EV penetration targets (in line with regulators concerns of costs being incurred and benefits realised within single 5-year 'price control' periods). Here, we consider an investment spread over the 3 years from 2027-2029. But, given the discussion in Section 3, we also consider a scenario where investment is spread over 12 years from 2021-2032 to permit a smoother adjustment.

In consultation with one of the UK network operators (SP Energy Networks) we have determined that only one-third of the investment is spent in the UK, limited to activity in the domestic Construction sector. All other equipment required are imported from the rest of the world (ROW). Thus, while UK (commercial, public sector and household) consumers must repay pay the total investment value (£2.7billion) over 45 years for the life span of the asset, only £900m of total spend is made in the UK. Our primary focus under this scenario is the 20% of UK households on the lowest annual incomes, given that the main direct impacts of this group (least likely to be participants in the initial uptake of the EV roll-out) may be expected to accrue for mainly from the need for consumers to repay the investment cost.

For the second stage we focus on how to consider the benefits realised through the EVs roll-out and this is when we adopted similar model specifications as (Figus et al., 2018). In contrast to Figus et al. (2018), EVs are enforced into the model as an exogenous demand shock. In addition, we also include efficiency improvement using information from TIMES

as discussed in (Calvillo and Turner, 2019), where EVs are expected to deliver monetary value overtime. Smoothing-out the upgrade of the EV at 2% in five-year blocks to capture step changes in the motor vehicle manufacturing sector. One source of expansionary impacts on the wider economy from the EV uptake is the efficiency gain in personal transport, which may free up income to spend on other sectors in the economy. Such that spending on vehicles and fuel does not simply involve a substitution between EVs and petrol/diesel vehicles. Rather, EVs become increasingly more efficient in using electricity to deliver the same number of miles (20% efficiency gain by 2030). We focus on the impacts in four years of particular interest: 2025, 2027 and 2030 (i.e. during the period up to the projected 20% penetration) and 2040, ten years on. Note that when we considered impacts beyond 2030 (and 2032, the end of investment activity), we are still only considering the impacts and economic adjustment in response to the initial phase network investment and 20% EV penetration.

4.2 What elements of the model specification are important?

Figus et al. (2017, 2018) discuss in detail (in appendix) the fuller model specification of the UK-ENVI. Here we adopt the same broad configuration, in terms of national fixed labour supply, forward looking producer, myopic consumers and export demand. Similar to Figus et al. (2017), we define the general form and structure of the UK-ENVI model as:

4.2.1 Consumption

The multilevel consumption component of the model describes consumption decision of each representative household expressed in general form as:

$$C_t = Y_t - S_t - HTAX_t - CTAX_t \qquad (1)$$

Where C denotes total consumption, *Y,* income, *S*, savings, *HTAX* income tax and direct taxes of consumption, *CTAX*. t denotes time, which is considered to be one year (given that

underlying data are annual). We assume the consumers are myopic[3] and their intertemporal

utility function is a nested constant elasticity of substitution (CES), where at each node

consumption decisions depend on relative prices and on the elasticity of substitution of this

type:

$$C_{h,t} = \left[\delta_h{}^E \left(\gamma_h EC_{h,t} \right)^{\frac{\varepsilon_h-1}{\varepsilon_h}} + (1 - \delta_h{}^E) TNEc_{h,t}^{\rho e} \right]^{\frac{\varepsilon_h}{\varepsilon_h-1}} \qquad (2)$$

In equation 2, ε is the elasticity of substitution in consumption, which captures the degree to

which consumers substitute energy goods. EC, non-energy and transport consumption,

TNEC, δ ∈ (0,1) is the share parameter and γ, is the efficiency parameter of energy
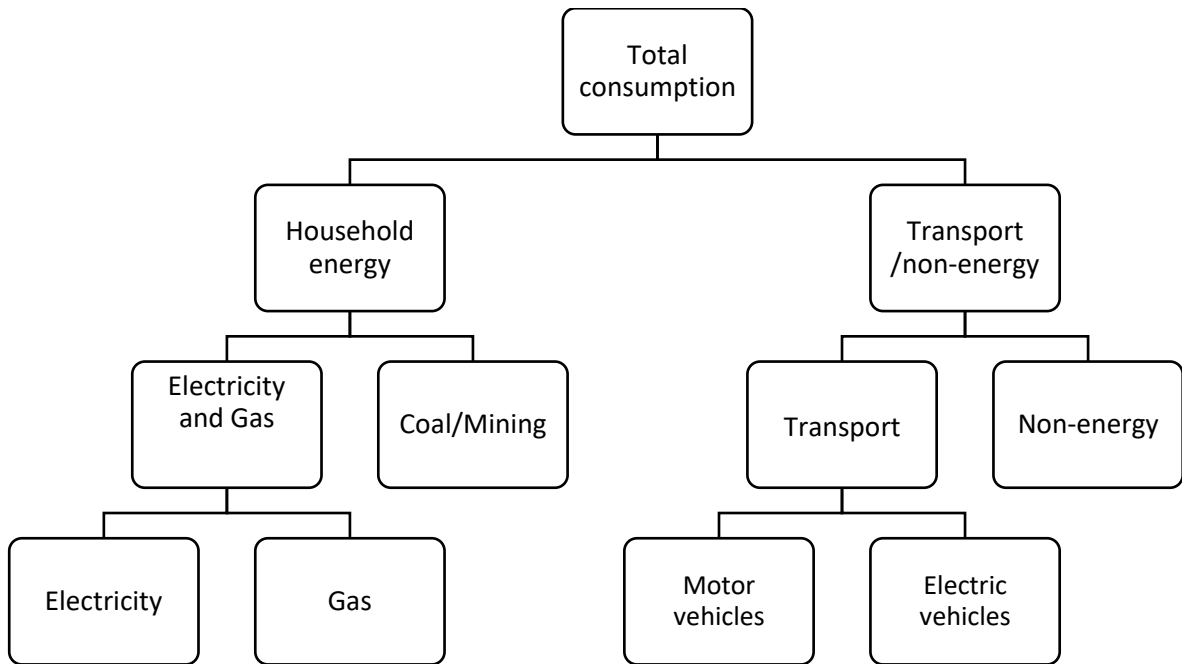
consumption.

Figure 1 illustrates the consumption structure in the UK ENVI model. Each household

allocates consumption between household energy (energy used for heating, lighting and other

residential uses) and non-energy. Consumption of energy is a constant elasticity of

substitution (CES) combination of electricity and gas A key issue here is how the price of

electricity is affected by the cost of investment being passed on to consumers. However, this

applies to commercial users also, so we return to how this impact the model specification in

Section 4.2.3. The main innovation in this paper is the right-hand side of the consumption

structure. In particular, the transport level and how EVs enters the model. EVs is enforced

into the model as an exogenous demand shock using Leontief Function where private

transportation is split into electric vehicles and motor vehicles.

$$ET_t = a_t^{ET} T_t \frac{P_t^T}{P_t^{ET}} \qquad (3)$$

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[3] This means consumer base their spending decisions mostly on current income available rather than on future
discounted utility of consumption (see Lecca et al., 2013).

Where ET_t represents electric transportation in any given year. As can be seen in equation (3) electric transportation is determined as a share a_t^{ET} of the total private transportation T_t, which, as already discussed, is exogenously determined in our model.

Figure 1. Structure of consumption

4.2.2 Production structure

Figure 2 illustrates the production structure in each of the 30 sectors in the UK-ENVI framework. It reflects the classical KLEM nested CES production function, where the input decisions in each sector involve a CES relationships between inputs of intermediate goods, labour and capital. In each sector, intermediate inputs and value-added produce total output. Intermediate inputs are a combination of energy and non-energy. Capital and labour form value-added. Energy is divided into electricity and non-electricity.
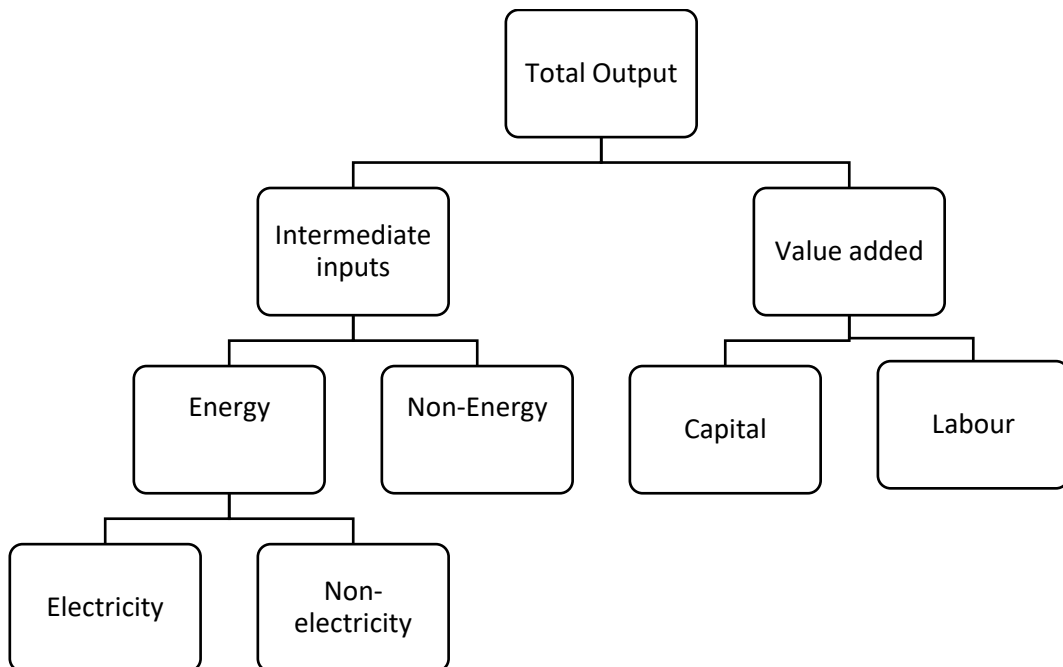
We assume that producers have perfect foresight (i.e. they are forward looking). In this case, producers anticipate that the funding for the network upgrade and reinforcement is one off and

no addition network funding to follow. Capital shocks accumulate over time through investments. In this version of the model investment decision follows Hayashi (1982), which describes maximization of the value of firms, V_t, subject to a capital accumulation function $\dot{K}_t$, so that

$$Max \sum_{t=0}^{\infty} \frac{1}{(1+r)^t} \left[\pi_t - I_t \left(1 + g(\omega_t) \right) \right] \text{ subject to } \dot{K}_t = I_t - \delta K_t \tag{4}$$

Where π_t denotes firms' profits, I_t is private investment $g(\omega_t)$ is the adjustment cost function, with $x_t = I_t / K_t$ and δ is the depreciation rate. The solution of the problem gives the low of motion of the shadow price of capital λ_t and the adjusted Tobin's q time path of investment (Hayashi, 1982)

Figure 2. Production Structure

4.2.3 Labour market

The UKENVI model allows for different assumption regarding the labour market. It comprises mainly of three labour market closures. These include wage bargaining, fixed real wage and fixed nominal wage. For the simulation result presented here we focus on the implications with fixed nominal wage. This because there is no indication that employees are in a position to effectively negotiate/bargain their wages under such investment scenarios relating to EV-roll out. However, as discussed in section 6, under possible sensitivity analysis to be conducted, in a case of longer investment beyond 2030 there is a need to consider alternative labour market closures (e.g. wage bargaining) and the impacts on the wider economy. The wage setting with fixed nominal wage is determined as follows:

$$w_t = w_{t=0} \qquad (5)$$

where nominal wage for the time period, w_t is constant and unchanging.

4.2.4 Impact of network improvement on prices

In our simulations, the UK component of the network investment is introduced through an increase in exogenous final demand for construction sector output. However, the full cost of investment spend (including the larger imported share) of the network upgrade to support the roll-out of EVs is passed on to the consumers/electricity users via higher electricity bill until the full investment cost is repaid. Thus, we outline how we have captured this increase in electricity price and electricity demand in equation 6

$$ELE_{h,t} = \delta_h^{ele\,\rho^{eg}} \cdot \left(\frac{Peg_t}{Pele_t}\right)^{\rho^{eg}} \cdot EG_{h,t} \qquad (6)$$

In (5), ELE is household demand for electricity, EG is the composite of electricity and gas, P_{ele} and P_{eg} are the prices of electricity and of the composite good electricity and gas, δ_h^{ele} is the share of electricity and ρ^{eg} is the elasticity of substitution between electricity and gas.

$$VVele_{j,t} = \left(A^{E \rho_j^E} \left(\delta_j^{vvele} \right) \cdot \frac{PE_t}{Pele_t} \right)^{\frac{1}{1-\rho_j^E}} \cdot VVEN_{j,t} \qquad (7)$$

Similarly, in (7) VVele is electricity demanded by each industry in the economy j, A^E is a productivity parameter, ρ_j^E is the elasticity of substitution between electricity and non-electricity, PE is the price of the composite good energy, and VVEN is industrial demand of total energy.

In the model the price of electricity is endogenous and is a function of all the other prices in the model. Agents in the model pay the same price P_{ele} as can be seen in equations (6) and (7). In order to increase the revenues from the sales of electricity and pay for the network upgrades, electricity supplying firms increase the price P_{ele} and introduce a mark-up as follows:

$$P_{ele} = P_{elemc} \cdot (1 + \theta) \qquad (8)$$

Here P_{elemc} is the price of energy in a perfectly competitive and equals the marginal cost of producing and supplying electricity, and θ is a mark-up. The setting is similar to a simple monopolistic pricing model. The difference between the two prices gives us the marginal profit rate of the firm.

$$mp = P_{ele} - P_{elemc} \qquad (9)$$

If we multiply the marginal profit rate by the total revenue from selling electricity to firms and households (Q_{ele}) we have the total profit which is set exogenously and equals the expenditure necessary to reinforce the network (NTW).

$$\overline{NTW} = mp(P_{ele} \cdot Q_{ele}) \qquad\qquad (10)$$

Here, NTW is exogenously determined and equals the expenditure necessary to upgrade the electricity network, Q_{ele} is determined by demand functions of households, firms and Government. When NTW is different from zero, the mark-up θ will increase by how much is necessary to get the marginal profit that is necessary to raise sufficient funding to pay for the network improvement. To simulate the increase in electricity price we substitute the price of electricity defined in equation (8) in (7) and (6) by setting NTW (9) equal to £2.7billion. However, we assume that while the expenditure takes place in 3 or 12 years, the repayment is spread across 45 years. In year 46, the price mark-up reduces to zero and the economy gradually approaches the long-run equilibrium.

5. Simulation results

5.1 Summary of scenarios simulated

We break the CGE simulation work into two stages. Scenario 1 focuses only on the impacts of the investment spending on electricity network upgraded that is required to support 20% EV penetration across the UK private transportation fleet without the uptake of EVs actually taking place. As explained, above, we base the level of spending simulated on mixed charging scenario, which assumes that 60% of EV charging is decentralised so there is the need for more extensive distribution network, while 40% of charging is centralised and therefore the need for distribution network is limited. The scenario is informed by, National Grid (2018) with the £2.7billion investment required to support 20% EV roll-out by 2030 determined via a TIMES simulation reported in Calvillo and Turner (2019). However, as discussed in Section 3, the timeframe over which the spending on network upgrade takes place will affect the anticipated impacts of the investment spending. Thus, we have two sub-

scenarios, Scenario 1a and Scenario 1b. In Scenario 1a assumes the spending takes place over the 12-year period between 2021 and 2032. Scenario 1b assumes that the entire spend and upgrade programme takes place within the 3-year period 2027-2029. In both cases, the total £2.7billion cost, £0.9billion of which is spent domestically (in the UK Construction sector), is recovered via electricity bills across a 45-year period from the first year of the investment (coincides with the life-span of the assets developed). See Table 1 for a summary.

Table 1. Breakdown of investment spending and repayment

a	b	c	d	e
	(a/45 years)	(0.33*a)	(c/12 years)	(c/3 years)
Total investment	Repayment (per year)	Total spending in the UK	UK spend (per year)	UK spend (per year)
£2,700m	£60m	£900m	£75m	£300m

Scenario 2 – where we have Scenario 2a and 2b incorporating the alternative investment timeframes in Scenario 1 - introduces consideration of how the roll-out of EVs affects the anticipated impacts. Here, we assume that there is a gradually increasing percentage of EVs is used to meet the private transportation needs, replacing the conventional internal combustion engine vehicles fuelled with petrol or diesel. The EV penetration is assumed to start at 2% in 2021 and expand by 2% each year until it reaches 20% in 2030. We also incorporate increasing efficiency in the EV fleet. This reflects conditions in Calvillo et al.'s (2019) TIMES analysis that we draw data from. That is, by 2030 EVs will be able to cover a longer distance per unit of energy compared to what they can achieve now. We introduce this in step changes, where the efficiency of EVs improve, compared to present levels, by 11% in 2021, 16% by 2025 and 20% by 2030.

5.2. Scenario 1: Impact of £2.7billion spending on electricity network upgrade to support EVs roll-out on key macroeconomic variables, with £0.9million spending in the UK Construction sector

Table 2 summarises some key macroeconomic impacts, with the first four numerical columns reporting for the case (Scenario 1a) where the network upgrade spending is spread across a 12-year period (2021-2032), focussing on: the first year (short-run) impacts (2021); 2030 (the year that the 20% penetration is expected); and 2040 (ten years on). 2027 is introduced for purposes of comparison with the latter three columns, which report results for the case (Scenario 1b) where the network upgrade spending is spread across a 3-year period (2027-2029). All results in Table 1 are percentage changes relative to the base year (SAM 2010) values.

Table 2. Percentage change in key macroeconomic variables from a £2.7billion investment spending to upgrade the UK electricity network

	Scenario 1a (12-year investment)				Scenario 1b (3-year investment)		
	2021	**2027**	**2030**	**2040**	**2027**	**2030**	**2040**
GDP	0.000	-0.001	-0.002	-0.006	0.004	-0.014	-0.007
CPI	0.003	0.006	0.006	0.004	0.007	0.013	0.005
User cost of capital	0.009	0.004	0.004	0.002	0.035	0.006	0.002
Unemployment Rate	-0.013	-0.010	0.007	0.090	-0.146	0.140	0.094
Employment	0.001	0.001	0.000	-0.006	0.009	-0.009	-0.006
Import	0.002	0.003	0.001	-0.004	0.016	0.003	-0.004
Export	-0.003	-0.008	-0.008	-0.006	-0.010	-0.022	-0.007
Electricity output	-0.043	-0.062	-0.063	-0.067	-0.041	-0.073	-0.067
Construction output	0.029	0.043	0.035	-0.009	0.111	0.002	-0.009
All other output	-0.002	-0.004	-0.005	-0.007	-0.002	-0.015	-0.007
Price of Electricity	0.084	0.104	0.105	0.104	0.088	0.107	0.104
Marginal cost of electricity	0.012	0.032	0.032	0.031	0.015	0.035	0.032
Household real spending	-0.002	-0.003	-0.004	-0.007	0.003	-0.013	-0.007

The results show that the 'demand shock' of the £0.9billion spending in the UK Construction sector to enable the network upgrade, accompanied by the need to repay the 2.7billion (albeit over 45 years) causes some contraction in the economy from the outset. This is due to both the binding constraint on the labour supply (with only the pool of unemployed labour providing excess capacity), the short-term constraint on capital, and the fact that forward-looking producers anticipate that the demand boost is time limited. The nominal wage is assumed fixed, but the user cost of capital is driven up as demand for the output of the Construction sector, and its upstream supply chain rise from the outset. This puts upward pressure on prices across the economy, as reflected in the CPI. Export demand contracts and there is a net decrease in output in all sectors except the Construction sector.

The biggest negative shock in Table 2 is reported for 2030 when the spending is condensed in a 3-year time frame ending in that year (Scenario 1b). Here, there is a contraction of 0.73% in Electricity sector and a further 0.15% in all other sectors but Construction. This is offset only very slightly in 2030 as resources begin to shift away from that sector in anticipation of the end of the spending programme. By 2040 the contraction eases, and more or less equalises over the two cases reported. Nonetheless (while it is not reported in Table 2), the cumulative loss to UK GDP within the 2021-2040 timeframe is notably larger (£1.33billion) when the spending is condensed in a 3-year period under Scenario 1b relative to that when it is spread over 12 years (£0.87billion).

Our key focus, however, at this stage (prior to consideration of benefits emerging due the EV roll-out) is the impact on UK household incomes, and low-income consumers in particular. The results in Table 2 show that under either scenario household losses are generally proportionately greater than GDP losses. This is due to the fact that households have to directly repay a share of the investment through their energy bills (in addition to paying via

the prices of other goods and services). The impact of the repayment is reflected in the fact that the increase in the price of electricity is notably larger than the increase in the marginal cost of electricity (which is impacted by the pressure that the expansion puts on the user cost of capital). It is only in the first year of the spending programme, and only under Scenario 1b, that the annual spend in Construction is sufficiently big to deliver gains to households (largely through direct and supply chain employment and wage income) to deliver a net positive impact on household real incomes, reflected in the 2030 result in Table 2. This is small (0.004%) and in fact we find that gains are only realised in the lowest household income group (bottom quintile).

Figure 3. Net change in per household real income of £2.7bn network upgrade investment occurring between 2027 and 2029
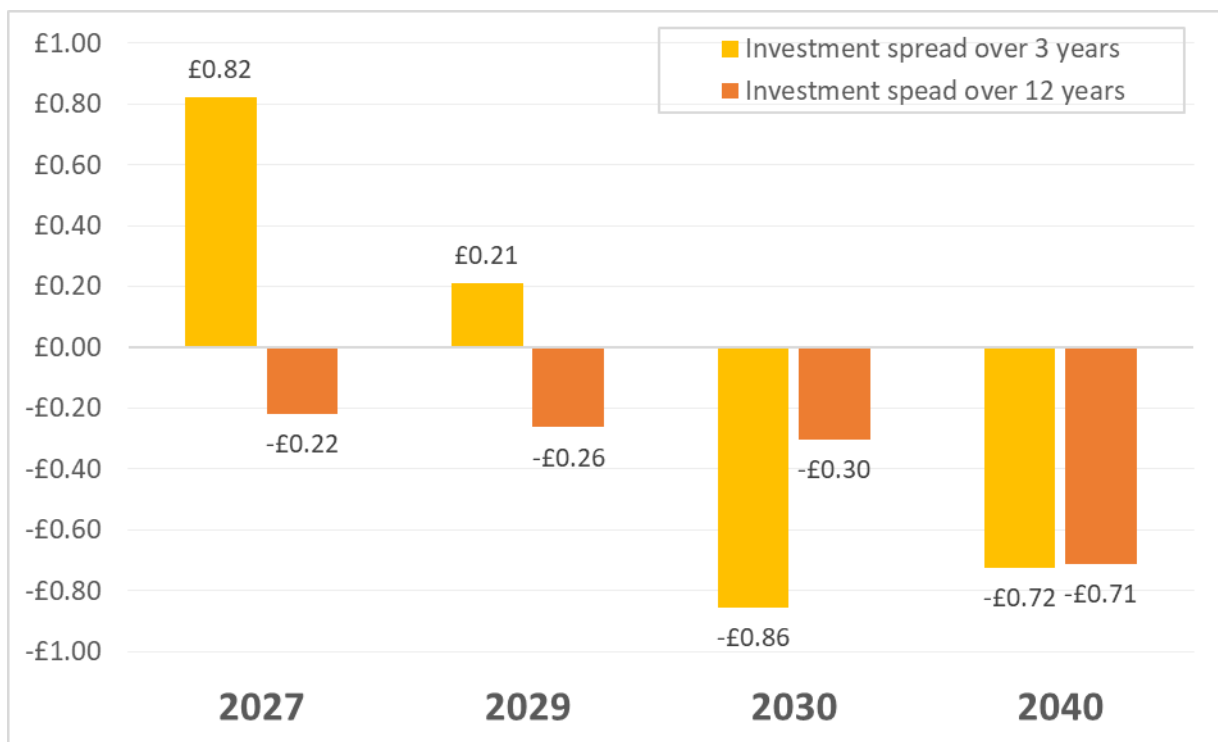

Figure 3 captures the net change in per household real income (take home wage) of the 20% of UK households with the lowest annual incomes that results from (i) the investment stimulus to the economy; (ii) the need to repay that investment. Here we see that, while worse

for the economy as a while, the UK's lowest income households may actually experience minimal net short terms gains in 2027 (82 pence per household). But by the end of the investment period in 2030, this becomes a loss of 86 pence, compared to 30 pence in the same year if the investment is more spread out. Generally, we find UK households with higher incomes tend to lose more, both because of the greater absolute impact on what are higher energy bills overall, and the fact that they are more exposed to changing economic conditions. This may be expected given that wage and capital incomes are more important sources of income to better off households (Figus et al. 2017; Turner et al 2018b).

6.2 Scenario 2: Combined impact of £2.7billion spending on electricity network upgrade and 20% EV penetration by 2030

For the second stage of our analysis, we focus on the realised impacts from the investment stage (as in Table 2) – and the need to repay that investment - combined with the 20% EV roll-out being achieved by 2039. The combined impacts on key macroeconomic variables are shown in Table 3, the format of which corresponds to that of Table 2.

The key feature to note in comparison to Table 2 is that adding introducing the EV roll-out enabled by the investment, generally results in a sustained positive impact on GDP, aggregate output (net across all sector) employment, and household incomes. This is the case whether the investment is spread over 12 or 3 years, but with slightly stronger performance under the former case (albeit with the gap narrows between the cumulative GDP impact across the 2021-2040 timeframe, with a 1.6bn real gain under the 12-year case and £1.56billion in the 3-year case.

On the other hand, the bigger boost to domestic demands does put more pressure on the constrained system in the early periods, so that the increase in the CPI is generally around double in Scenarios 2a and 2b (Table 3) relative to what is reported for Scenarios 1a and 1b (Table 2). Thus, the decrease in export demand is notably larger in the earlier periods, where

the investment activity is still taking place, and remains slightly larger through to 2040. It is the sustained boost in domestic demand through the roll-out of EVs that permits a sustained boost to GDP to be supported by a lasting boost to employment and household real incomes.
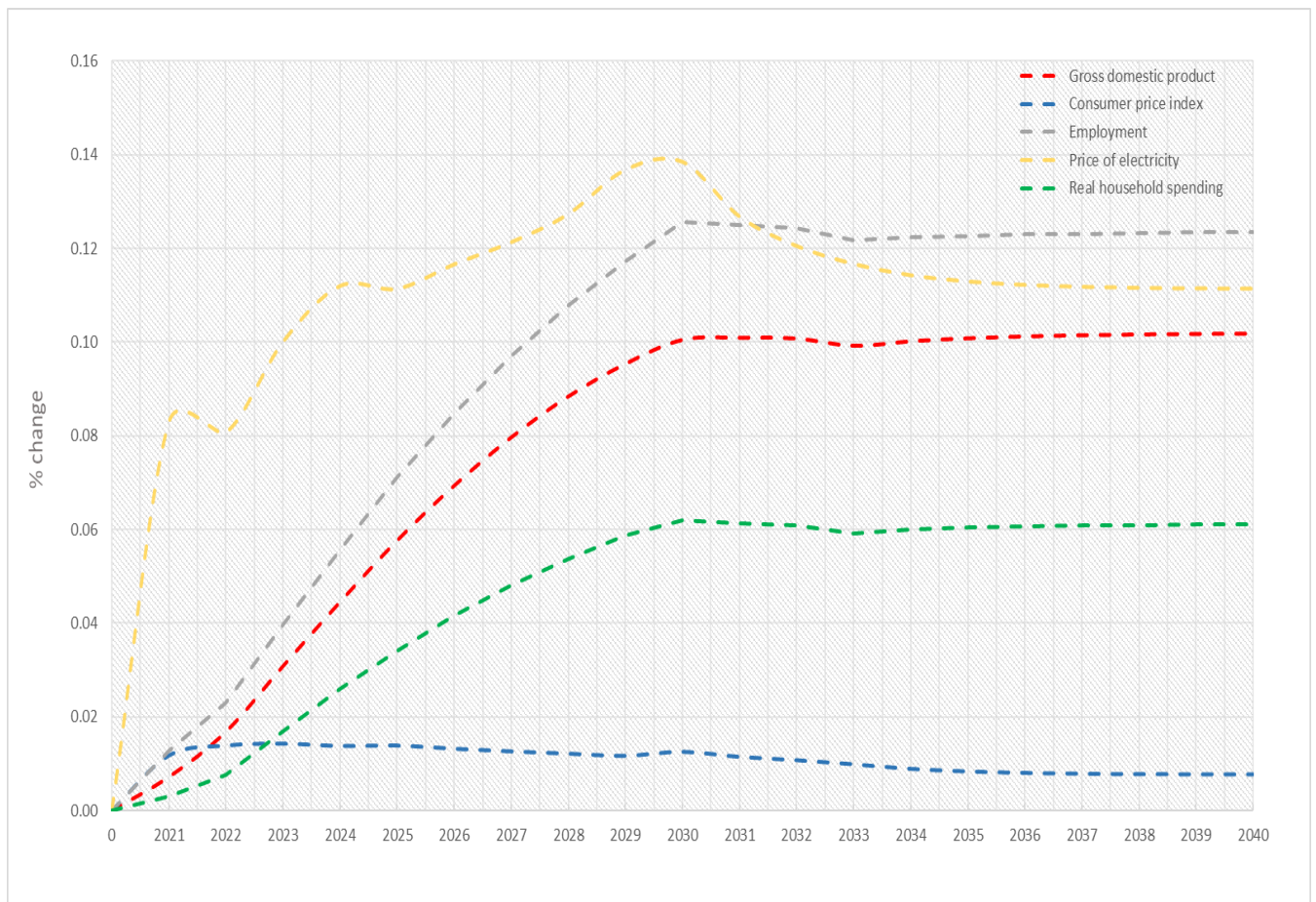
Table 3. Percentage change in key macroeconomic variables from a £2.7billion investment spending to upgrade the UK electricity network and the enabled 20% EV roll-out

	Scenario 2 (12-year investment)				Scenario 2 (3-year investment)		
	2021	2027	2030	2040	2027	2030	2040
GDP	0.007	0.080	0.101	0.102	0.085	0.088	0.101
CPI	0.012	0.013	0.013	0.008	0.014	0.020	0.008
User cost of capital	0.027	0.011	0.010	0.005	0.042	0.012	0.005
Unemployment Rate	-0.202	-1.521	-1.967	-1.934	-1.657	-1.834	-1.930
Employment	0.013	0.097	0.126	0.123	0.106	0.117	0.123
Import	0.032	0.016	-0.021	-0.030	0.029	-0.020	-0.029
Export	-0.022	-0.020	-0.009	-0.008	-0.022	-0.023	-0.009
Electricity output	-0.092	1.955	2.992	3.055	1.976	2.983	3.054
Construction output	0.083	0.165	0.151	0.103	0.233	0.118	0.103
All other output	0.001	0.065	0.086	0.087	0.067	0.076	0.086
Price of Electricity	0.083	0.121	0.138	0.111	0.105	0.141	0.112
Marginal cost of electricity	0.012	0.032	0.032	0.031	0.015	0.035	0.032
Household real spending	0.003	0.048	0.062	0.061	0.054	0.053	0.061
Household consumption of electricity	-0.189	4.546	7.065	7.079	4.560	7.059	7.079
Household consumption of refined fuels	0.004	-10.582	-16.785	-16.810	-10.573	-16.792	-16.810
All other household consumption	0.012	0.025	0.026	0.023	0.033	0.018	0.023

In terms of what households consume, the results in Table 3 reflect the shift from petrol and diesel to electric fuelling, with an increase in household consumption of electricity, and continued drop in spending on the outputs of the refined fuel distribution sector. By 2030 household consumption of electricity increase by 7.1%, while refined fuel consumption fall by 17% with the investment spread over 12-year or 3-year investment.

Figure 4, plots the trend and impacts on key macroeconomic variables from the investment in network infrastructure upgrade and enabled 20% penetration roll-out of EVs for the case where the investment spending is spread over 12 years (Scenario 1a). Note that the increase in real household spending always trails GDP expansion. This is because, households continue to repay the network investment cost via higher energy bills, which is exacerbated by the fact that the uptake of EV increases demand for electricity, putting further upward pressure on prices.

Figure 4. Net impacts on wider economy of 20% EV penetration by 2030 and required network investment (Scenario 2a)

However, perhaps the key result driving the macroeconomic gains reported above, is what happens to the composition of activity in the UK economy. To illustrate this, Figure 5 presents the percentage change in full time equivalent (FTE) employment across sectors in

the UK economy for Scenario 2a. We focus on the impacts in four years of particular interest:

2025, 2027 and 2030 (i.e. during the period up to the projected 20% penetration) and 2040,

ten years on. Note that when we considered impacts beyond 2030 (and 2032, the end of

investment activity), we are still only considering the impacts and economic adjustment in

response to the initial phase network investment and EV roll-out to 2030.

Figure 5. Net impacts on sectoral employment of 20% EV penetration by 2030 and required network investment (Scenario 2b)
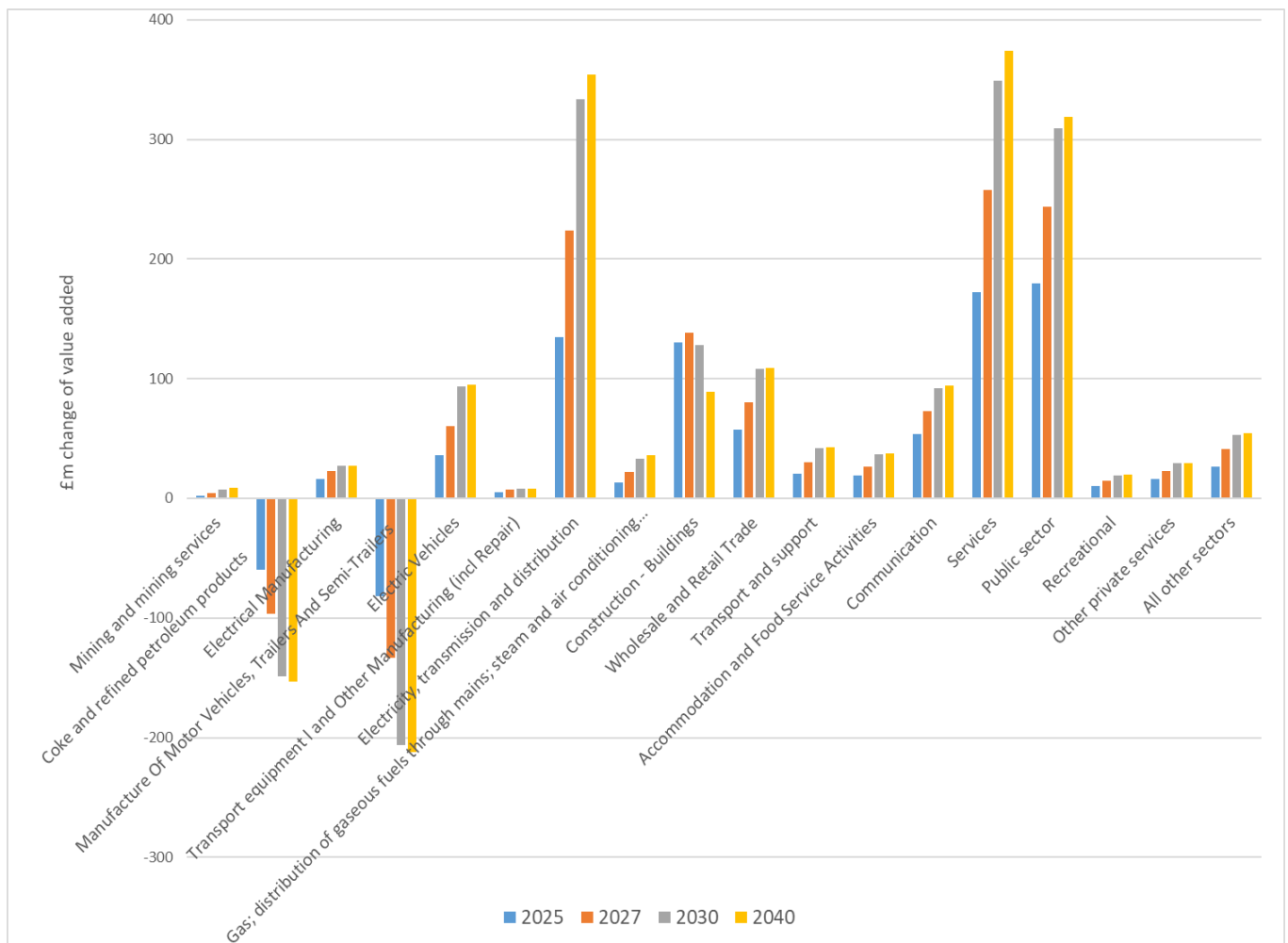

Figure 5 reflects the fact that (in line with arguments resulting from the input-output analysis

of Turner et al., 2018a) the key driver of wider economy gains reported in Table 3 is the

greater reliance on domestic (UK) supply chains in supporting fuelling of electric rather than

petrol and diesel cars. In all periods, the greatest employment gains are enjoyed in the

electricity sector itself and in public and private service sectors. The total gross employment

gains, which are maximised in 2040 at 3,071 jobs, are set against a gross sustained loss of

115 jobs in the same period. These job losses are confined to the manufacture and fuelling of petrol/diesel vehicles and offset in other sectors.

Figure 6. Net impact on value of sectoral gross value added from 20% EV penetration by 2030 and required network investment (Scenario 2a)

The diversity and spread of the UK supply chain supporting the electricity sector are reflected in the finding that the biggest employment gains are in the wider public service sector, which includes research, education, health and other public services and gains a sustained increase of 874 jobs by 2040. The wider private services sectors, which includes everything from finance/insurance to legal and real estate activities etc. ultimately gains and sustains an additional 430 jobs. The electricity (generation, supply and distribution) industry itself is

more capital intensive, but still gains 512 jobs by 2040. This change in the composition of activity across industries with differing labour intensities is also reflected by the larger and sustained proportionate boost in employment over GDP in Figure 4. On the other hand, the contribution of the electricity to the expansion to the expansion in GDP is better reflected in Figure 7, which reports the impacts on sectoral gross value added (GVA) at sectoral level.

6. Conclusions

Generally, the analyses presented here serve to demonstrate the need to shift focus from the technology and investment concerns associated with large new low carbon initiatives to focus on how the new activity enabled may unlock, sustain and increase value in different parts of the economy. In the case of EVs, the results reported here raises questions as to whether we may have been missing a key source of value in terms of how we have fuelled our vehicles in the past. We have shown that a shift in household spending to fuel vehicles from more import intensive petrol and diesel towards the outputs of the electricity industry, which, in the UK at least, is a sector with stronger domestic supply chain linkages, will generate multiplier effects that allow the economy to expand. On the other hand, it is important to note that the expansion in UK GDP observed in our simulations is achieved at the cost of higher price levels and a drop in export demand for UK production.

A key next stage of our research is to subject the results reported here to sensitivity analysis. In terms of the costs on the wider economy imposed by the investment stage to facilitate electricity network upgrade, a key starting point will be to consider what may happen if producers anticipate a continued programme of investment. That is, we have confined our attention to the EV roll-out to 2030, which maps to only a 20% penetration, while UK Government targets require a more extensive uptake of EVs over the extended period to 2040. Similarly, network upgrade requirements and associated investment costs to 2030 and beyond will depend on just how smart and centralised the charging system can become. In

terms of conditions in the economy, while the national labour supply constraint is a standard assumption (and an increasingly more relevant one as the UK exits the EU), our assumption of fixed nominal wages, while motivated by wage conditions in recent years, may be crucial in terms of just how the capacity constraint impacts the economy's ability to expand.

But, at this stage, the initial results and analysis presented here allow us to draw a core policy-relevant conclusion. This is that UK policy makers and industry to consider to how to capitalise on the type of returns to low carbon development. Our results clearly show that the ongoing EV roll-out and other low carbon initiatives are likely to deliver the greatest gains where domestic capacity can be fully and effectively utilised.

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