HOW THE PACE OF ADOPTION OF ELECTRIC VEHICLE SMART CHARGING IMPACTS THE ENERGY SYSTEM?

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Abstract

The widespread roll-out of electric vehicles (EV) is one important action sought by governments around the world to tackle climate change and to improve air quality in urban centres. However, this extensive rollout of EVs is likely to bring important challenges to the energy system, potentially requiring new generation capacity and network reinforcements [1]. It has been recognised that the timing ('smart' vs 'dumb') of EV charging could potentially increase or mitigate the undesired impacts of the EV rollout [2]. In the case of the UK, it is expected that most cars and vans will be electric by 2050. Also, it is expected that by 2050, 75% of EVs will be charged in a smart way [3]. Currently, EVs represent around 7% of newly registered cars in the UK [4] and it is assumed that most of them are charged in a 'dumb' way, in free 'on the street' charging. So the path to reach the expected 75% smart charging is not clear.

Many studies have been developed to analyse the impact of smart EV charging. However, most of them do not consider different smart charging adoption pathways and normally they only analyse the implications of a large penetration of EVs in the power sector, not considering, for example, the changes on emissions, fuel use and consumer costs. The work developed in this paper aims to provide insight on this issue, analysing the implications of a large penetration of EV under different smart chaging adoption pathways, using the UK TIMES energy system model. Preliminary results show that the speed in which smart charging is adopted can have important impacts on the level of network investments, and thus higher costs for the final consumer; where a slow adoption of smart charging could result in around 70% extra network investment costs, relative to a faster implementation of smart charging.

Introduction

As part of their actions to tackle climate change and local pollution, a number of countries around the world are pushing ambitious targets to electrify transport [5]. For instance, the UK Government has moved forward to 2030 a previously set target of all new cars and vans to be effectively zero direct emission [6], and National Grid (the British Transmission System Operator) has revised its expectation to an almost full EV penetration on the private car fleet by 2050 [7]. Other countries have also increased their efforts in the decarbonisation of transport. For instance, Ireland, Iceland, Denmark and the Netherlands have set a similar ban on petrol and diesel cars by 2030, whereas Norway, which currently shows the largest EV uptake in Europe, has set the target for 2025 [8].

Such a major shift is likely to bring important challenges to the energy system, as the new electric load to charge EVs is likely to require new generation capacity and considerable network reinforcements. These changes will require important investments, the cost of which will ultimately be paid by consumers. Many studies have been developed to address these challenges, with particular focus on the impacts of a large penetration of EVs on the power network, using power system and network models. However, this neglects other potentially important impacts and, thus, policy implications outside the electricity sector. For example, the impact on fuel use, consumer costs and wider emissions. Similarly, EV charging strategies have been widely studied, analysing potential benefits for the power system, but the relative impacts of different smart charging adoption rates (i.e. how fast is smart charging implemented) has not received much attention and the focus has not extended beyond the power sector.

The objective of this paper is to provide insight on the potential impacts of the planned large-scale EV rollout in the UK in terms of network investments and emissions. We use the UK TIMES whole energy system model [9] to analyse a large EV penetration case. We have selected this model as it covers the whole integrated energy system (supply, conversion and demand, across all sectors: agriculture, services, residential, industry, transport) and not only the power sector. In this paper we consider two case studies: firstly, a case to analyse the impacts of different smart charging adoption rates, considering an EV penetration reaching 90% of total travelled car kilometres by 2050; and secondly, a case that analyses different EV rollout speeds to reach 100% penetration by 2050, following National Grid's Future Energy Scenarios (FES2020) [7].

The TIMES model is actively used to inform policy decision-making in the UK, and with the Scottish Government using a Scotland regional model version to identify decarbonisation pathways [10]. Also, National Grid (the British TSO) and the UK department for Business, Energy and Industrial Strategy (BEIS) use the UK TIMES framework for their analyses [11]. The work developed in this paper aims to provide policy-relevant insight on the wider effects of the electrification of transport, analysing the implications of a large penetration of EV under different charging scenarios, and discussing best practices on informing energy policy. We then propose and discuss further questions to extend and complement the analysis developed in this paper.

Methods

Modelling framework

The Integrated MARKAL-EFOM System (TIMES) is a bottom-up energy system-wide model, which considers all the processes of the energy system. The TIMES model generator is developed by the Energy Technology Systems Analysis Programme (ETSAP), which is a project run at the International Energy Agency [12]. TIMES has been used widely to analyse different policy questions including decarbonisation scenarios, as in [13], [14], or the energy system impacts of specific technologies and policies, as in [15], [16].

The UK TIMES model considers all the processes that transform, transport, distribute and convert energy to supply energy services (see Figure 1). The inputs (exogenous variables and parameters) of the model are: service demand curves, supply curves (e.g. primary energy resources such as wind power or availability of imports), and techno-economic parameters for each technology/process (e.g. technology efficiencies and availability factors, investment cost per capacity unit, O&M cost per unit of production, etc). The outputs (endogenous variables) include: energy and commodity flows and marginal costs, technology installed capacities, emissions, etc.

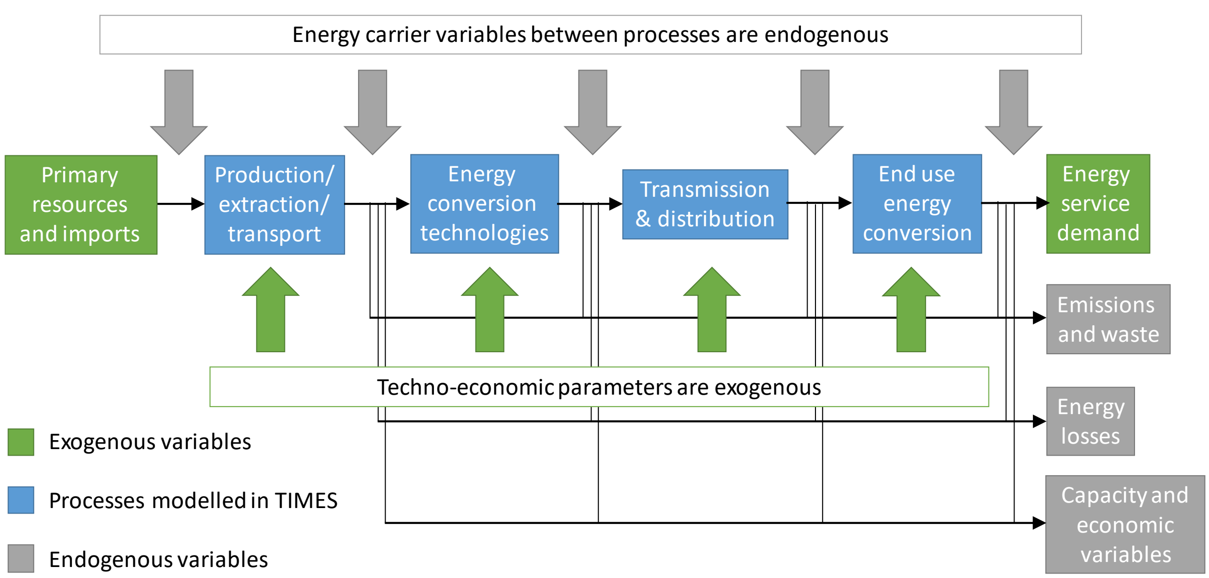

Figure 1. Modelling of the energy system in TIMES [17].

UKTM is a single region model of the UK, used for medium to long-term analysis of energy systems. The time horizon in UKTM runs until 2050, with time periods of 5 years, and taking 2010 as the base year. To reduce complexity in the optimization model, TIMES considers only some representative time-slices that work as an average of the elements of that time period. UKTM considers 16 time slices: four time divisions within a year representing seasons (spring, summer, fall and winter), and four daily divisions for each season (night, day, evening peak and late evening).

The sectors considered in the model include: industry (organised by subsectors: cement, pulp and paper, food and drinks, petrochemicals, etc.), agriculture and land use, transport, residential, services and the power sector. The power system in TIMES includes a very large number of generation technologies and also models the transmission and distribution networks. The representation of these networks is limited due to the single region aspect of UKTM. However, it is useful to assess if current network capacity would be enough to accommodate the expected generation and demand.

Moreover, UKTM is a partial equilibrium model-generator assuming perfectly competitive markets and full foresight. The model uses linear-programming to find a least-cost energy system (calculated as sum of investment, fixed and variable operation and maintenance (O&M), and import and export costs/revenues for all the modelled processes), able to meet specified energy service demands, according to a number of user constraints.

The model uses demand projections as the main driver of the energy system. In other words, the model finds the least cost energy system configuration (technology mix and energy flows) to meet the expected demand. So the technology selection by the model is based on the cost-effectiveness of the technologies, considering their performance, capital, operation and maintenance, and fuel costs. Also, to avoid 'penny-switching' (i.e. dramatic technology changes in a short period of time, triggered by a small cost saving), technology adoption constraints are set in the model trying to replicate realistic technology adoption scenarios.

A more detailed description of the UKTM model and its database can be found in [17], [18] and official TIMES documentation can be found in [19], [20].

Parameters required for this study

Table 1 shows the expected UK car transport demand up to 2050 used for this analysis. The table shows that there is an assumed growth of almost 50% of total private car and vans demand by 2050, relative to the year 2010. Note that these projections are based in travelled kilometres, which are independent of car type or ownership method. These car demand values are based on Department of Transport (DfT) Road traffic forecasts 2015 for England and Wales. This is assumed to be representative of the whole UK [21].

Table 1. Car transport demand projections.

	2010	2015	2020	2025	2030	2035	2040	2045	2050
Billions of travelled km	353.9	376.3	405.4	435.5	453.2	472.0	488.8	507.4	527.1
Demand growth Index (relative to 2010 level)	0%	6%	14%	23%	28%	33%	38%	43%	49%

Table 2 summarises the main EV parameters used in UKTM. The EV technical efficiency are expected to increase in the future, whereas vehicle upfront costs and operation and maintenance costs are expected to decrease. In particular, these costs are reduced considerably from the first commercial options in 2010 to current costs, and it is expected to continue to decrease in the future. These projections roughly align with the forecasts provided by Bloomberg New Energy Finance [22] and the International Energy Agency [23].

Table 2. EV parameters used in this study.

	CAR TYPE	2010	2020	2030	2040	2050
Lifetime (years)	All			12		
Technical efficiency (vehicle km/MJ)	EV	1.45	1.62	1.75	1.84	1.89
	Diesel	0.41	0.54	0.54	0.56	0.58
	Petrol	0.40	0.45	0.45	0.47	0.48
	Hybrid°	0.57	0.64	0.64	0.67	0.68
Vehicle cost* (k£/vehicle)	EV	43.21	22.06	20.92	19.77	18.63
	Diesel	12.84	13.06	13.39	13.39	13.39
	Petrol	12.49	12.39	12.62	12.62	12.62
	Hybrid°	16.59	13.13	13.13	12.97	12.81
Fixed operation & maintenance cost* (k£/vehicle)	EV	2.93	1.68	1.62	1.55	1.48
	Diesel	1.52	1.53	1.55	1.55	1.55
	Petrol	1.50	1.50	1.50	1.50	1.50
	Hybrid°	1.74	1.53	1.53	1.52	1.52

**2010 prices; °Non-plug-in hybrid vehicle*

Table 3 shows the considered capital investment, operation and maintenance costs per capacity unit for network reinforcements. These parameters are used to compute the total cost of all new network capacity implemented in the energy system as a result of the increasing EV demand. These costs parameters roughly align with different network reports including the analysis developed by Kiani Rad and Moravej [24], IEA ETSAP [25] and the Electricity Networks Strategy Group [26].

Table 3. Transmission and distribution network reinforcement cost parameters used in this study.

	Technical lifetime (years)	Investment costs* (m£/GW)	Fixed operation & maintenance cost* (m£/GW)
Transmission	40	628.26	6.34
Distribution	25	328.13	12.61

**2010 prices*

EV charging scenarios description

Case study 1: impacts of smart charging adoption rates

Figure 2 shows the EV rollout projection used for case study 1. For all scenarios, except the base case (with no EV penetration), we implement EV technology-use constraints to meet the car demand described in Table 1, but following the expected penetration of EVs shown in Figure 2, which is around 20% by 2030, 80% by 2040 and 100% by 2050. Note that this EV penetration scenario is based on the SPEN RIIO-T2 Electricity Scenarios 2018 consultation [27] and National Grid Future Energy Scenarios FES2020 [7].

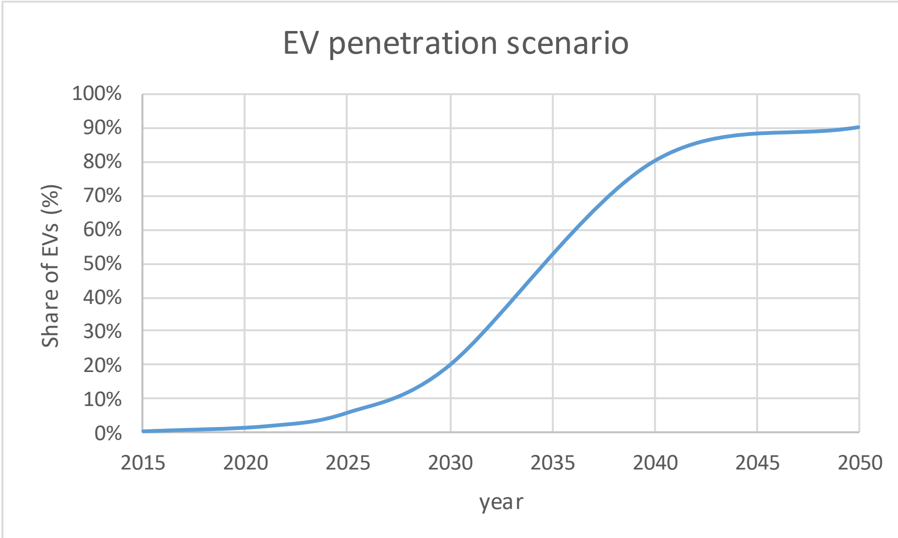

Figure 2. Considered EV penetration for case study 1

In this case study 1, a large EV penetration is assumed with a 75% of smart EV charging by 2050, based on National Grid's (the British TSO) Future Energy Scenarios [3], [7]. The three analysed scenarios vary in the adoption rate of smart charging, reaching the 75% of smart charging by 2050 at different paces (see Figure 3).

The results of the different scenarios are compared across one another and with a base case where no EV uptake is implemented. The impact of the EV smart charging adoption pace is analysed in terms of network investments, fuel costs and emission reduction.

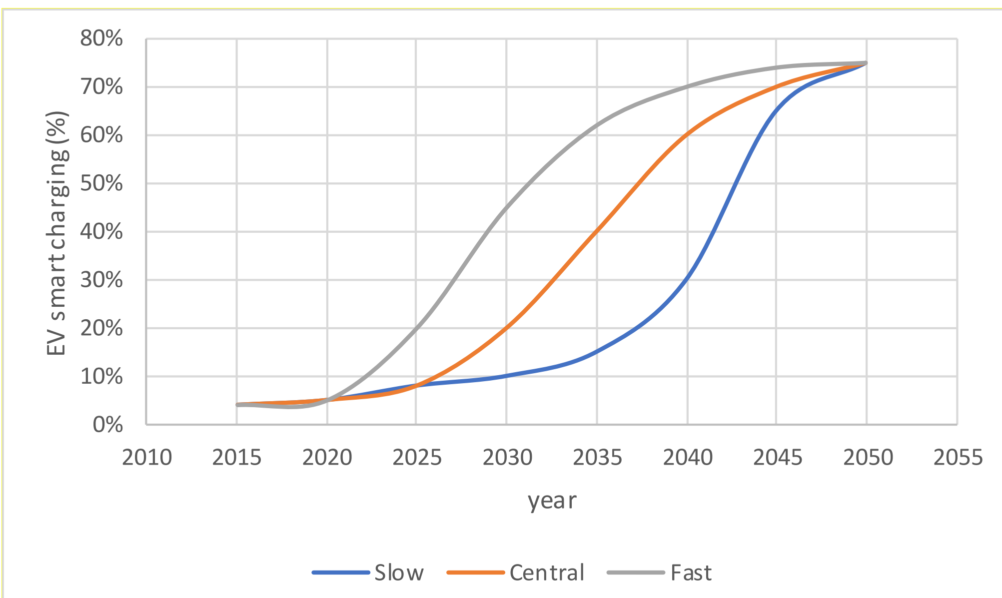

Figure 3. EV smart charging adoption scenarios for case study 1.

Case study 2: impacts of differen EV penetration pace

Figure 4 and Figure 5 show the EV uptake scenarios and EV smart charging adoption scenarios, respectively, for case study 2. These scenarios differ from those in case study 1 as they consider different EV rollout pathways: slow uptake, central uptake and fast uptake, with their corresponding smart charging assumptions, whereas in case 1, there was a single EV rollout scenario but different smar charging adoption rates scenarios. Note that these EV uptake scenarios are based on the FES 2020 scenarios of steady progression, system transformation and consumer transformation [7].

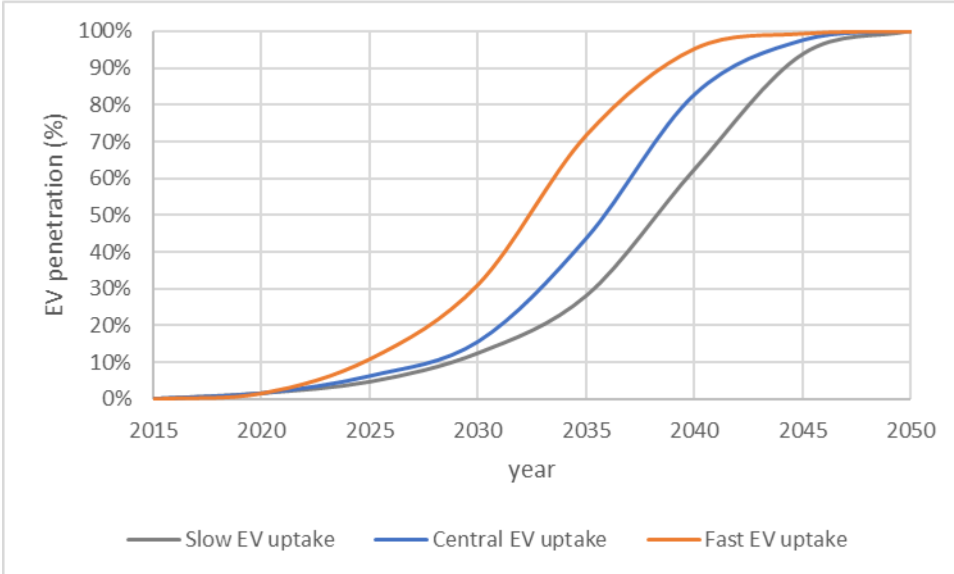

Figure 4. Considered EV penetration for case study 2.

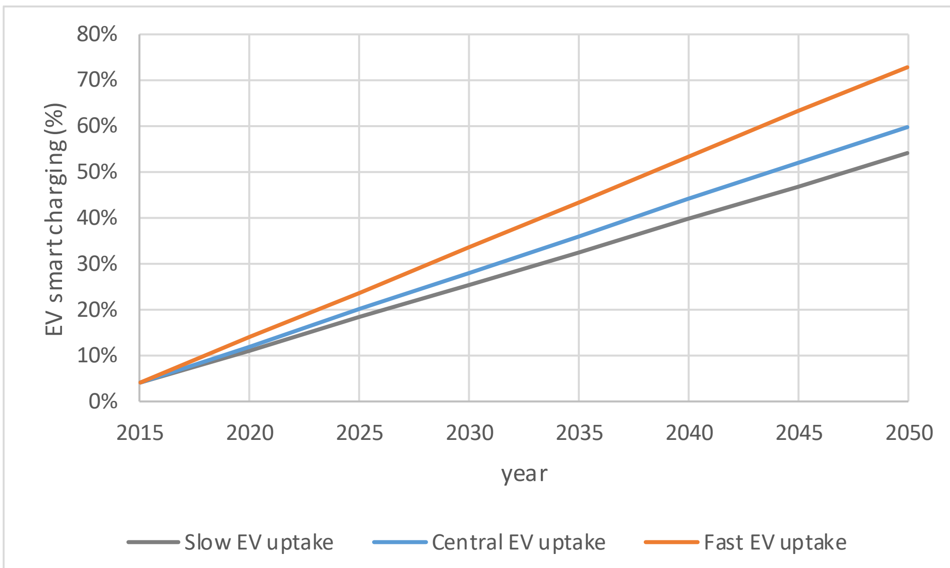

Figure 5. EV smart charging adoption scenarios for case study 2.

Results

Case study 1

Results show that these EV smart charging pathways produce very different results in terms of the timing and the level of network reinforcements. For example, Figure 6 shows the extra investments, relative to the base case, that need to be done on the network to accommodate the extra load produced by growing EV numbers. It can be noted that the investment patterns can change significantly in the different smart charging adoption scenarios, with the largest difference found in the slow adoption case (orange columns in Figure 6) with an almost double investment costs than the other cases.

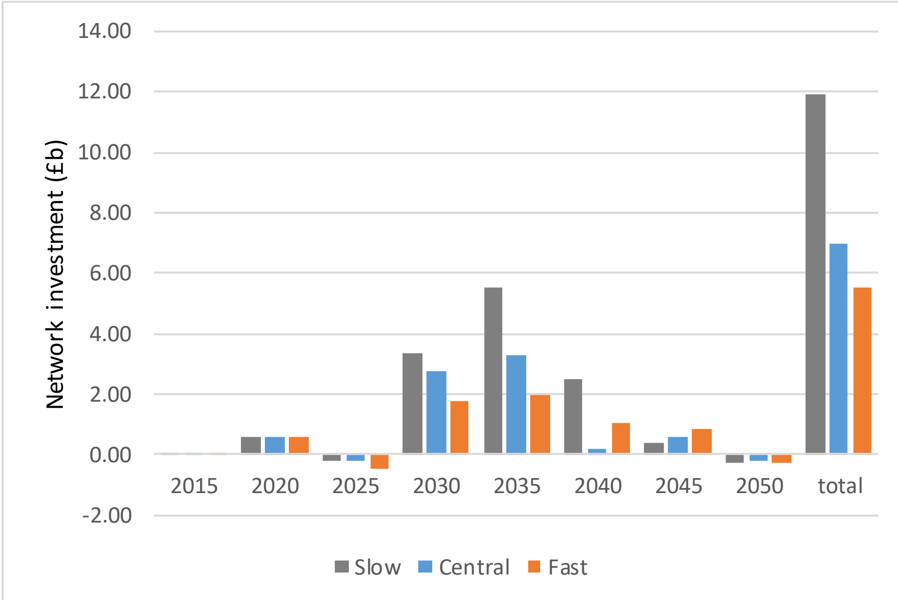

Figure 6. Case study 1: new extra network investments relative to the base scenario without EVs.

Figure 7 show the sectoral CO2 emisisons for the analysed EV smart charging adoption scenarios. Unlike on the investment levels, the overall emissions do not change significantly between EV scenarios. Also, relative to the base case, there is little overall reduction in emissions (around 2%). However, the sectoral changes in the transport sector and the electricity generation sectors present big changes.

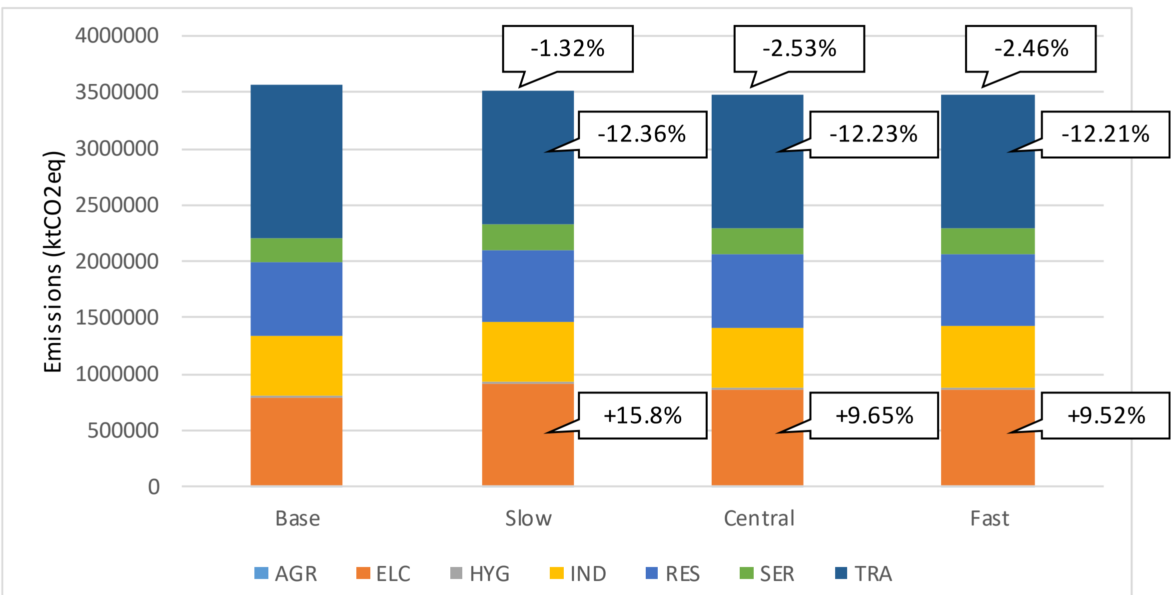

Figure 7. Case study 1: Sectoral CO2 emission changes for the analysed scenarios.

Case study 2

For the second case study, I have developed a similar analysis. Figure 8 shows the network investents requirements, relative to the base case without EV adoption. The total network investment needs range between £8b and £11b. this shows that the variation in smart charging adoption rates (see Figure 6) potentially has a bigger effect on investment needs than the EV uptake rates (as shown in Figure 8). However, the importance of the speed of the uptake is not negligible.

Additionally, the network investment costs are transferred to consumers as an increase in marginal costs (energy prices), so the 'fuelling' costs for car transport can be significantly different across scenarios. These and other relevant policy outcomes, such as emission reductions, are also important to take into account while designing energy tariffs and EV policies.

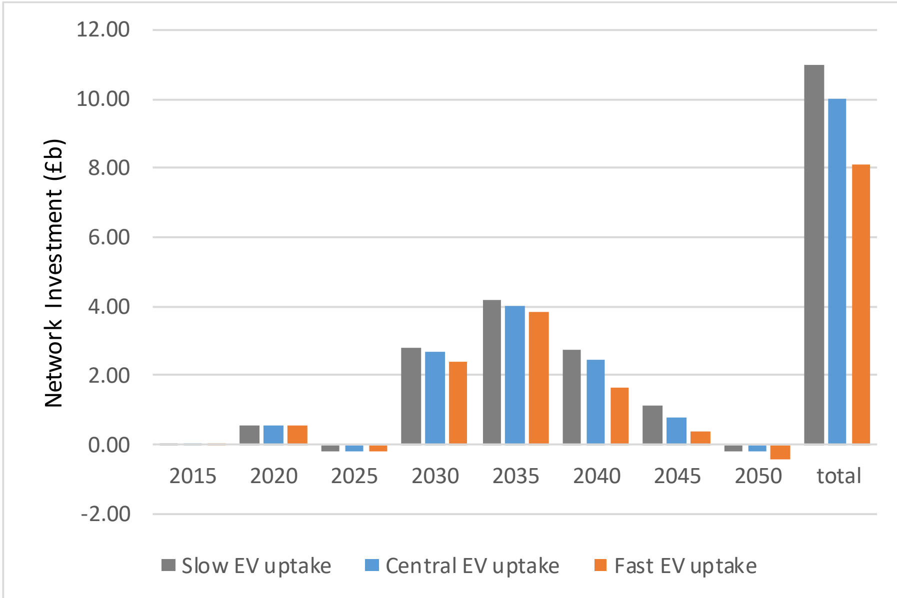

Figure 8. Case study 1: new extra network investments relative to the base scenario without EVs.

Regarding CO2 emissions, this case studyshows a similar picture than in case study 1, with a small overall decrement in emissions, relative to the base case. Also, there is a significant reduction on CO2 emissions on the transport sector and a similar increase in the electricity sector, which suggest an emissions transfer across sectors. This is an important phenomenom to consider when analysing long term decarbonisation plans and policies.

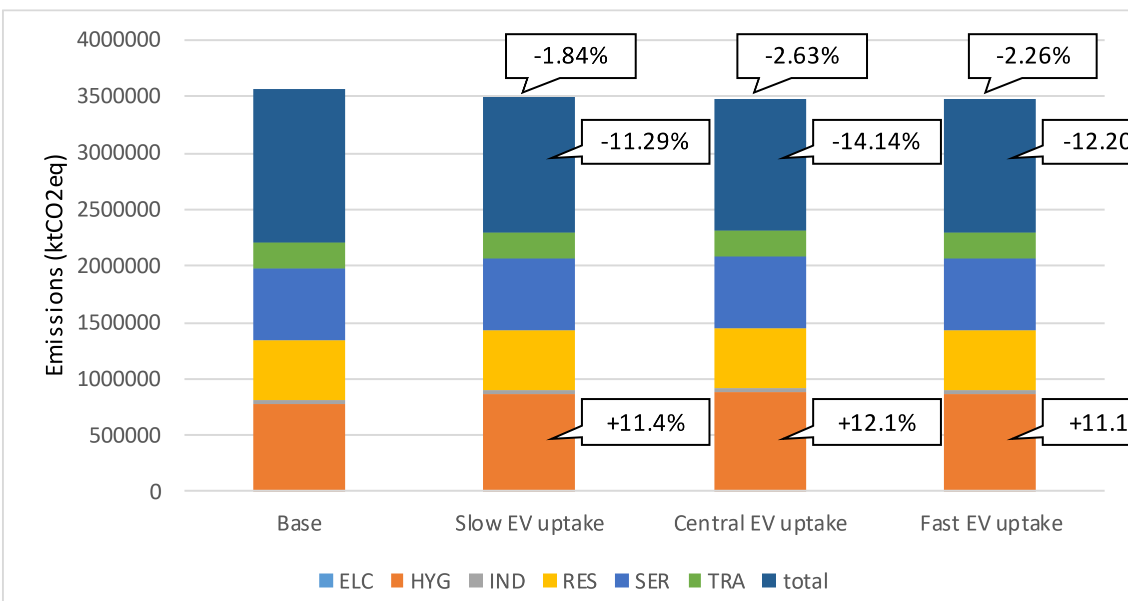

Figure 9. Case study 1: Sectoral CO2 emission changes for the analysed scenarios.

Conclusions

Even though the representation of the network in TIMES is limited, the study proposed in this paper provides some insight on the implications on network investments and energy costs of different EV smart charging adoption rates. An interesting result of this analysis is that not only the level of investment is affected, but the timing of those investments as well. This could have important implications for the economy, as large investments concentrated in a short period of time could create adverse effects in the economy due to labour and/or capital scarcity [28]. We believe that these scenarios provide a range of outcomes that may help policymakers and network operators to plan and find solutions that do not overburden consumers and facilitate the uptake of EVs.

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