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‘Disruption’ and ‘continuity’ in transport energy systems: the case of the ban on new conventional fossil fuel vehicles

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Keywords

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Abstract

The phasing out of the sale of new conventional petrol and diesel vehicles by a given date is one of a number of potentially disruptive policies that have been announced over the past five years. While the UK has opted for a target year of 2040 other jurisdictions have announced more challenging target dates (2025: Norway, Paris; 2030: Germany; 2032: Scotland) and scope (petrol and diesel, diesel only, non-electric). There is lack of robust analysis that examines the various targets and phase outs in terms of the key trade-offs in improving carbon emissions, air quality, and public health at various scales. There are also important issues around public acceptability, including how people buy cars and vans, how cars and vans need to be sold, accessed and utilised in order to accelerate turnover in the fleet. These need further investigation through the lens of ‘disruption’. This paper investigates a number of alternative futures around the proposed ban on conventional fossil fuelled vehicles in the UK. By doing so it explores how such a strategy/ban can be achieved while maximising ‘co benefits’; what the impacts might be if the Government were more ambitious; how much ‘disruption’ is needed; and what the implications of different consumer acceptability scenarios are. We used established modelling techniques and prospective scenario analysis to explore existing and alternative disruptive strategies with the view to achieve near ‘zero emissions’ and much improved air quality from light duty vehicles by 2050. The results suggest that the existing, relatively unambitious 2040 ban on internal combustion engine cars and vans can be achieved by essentially doing what we are doing anyway (continuous change) whereas more ambitious bans (e.g. 2030, and including hybrids) would require some ‘disruptive’ change within the existing socio-technical system. We conclude by discussing and mapping the policy options in terms of disruption for government, industry and consumers.

Introduction

The transport sector has a significant dependence on oil, with a share of 95 % of all global transport energy use in 2015, and this has not changed since the 1970s (IEA 2018). In the UK, energy use from transport has increased 16.1 % since 1990, against an economy-wide decrease of 4.1 % and net carbon emissions are unchanged (BEIS 2018; CCC 2018b). Transport is also the largest carbon-emitting sector of the UK economy with 28 % of greenhouse gas emissions in 2017 (BEIS 2018; CCC 2018b). As emissions in other sectors have reduced, transport has grown as a share of overall emissions with no net reduction since 1990 *vis a vis* a 43 % reduction for all sectors combined. A lack of progress with heavy goods vehicles and aviation persists, but the unexpected change is the increase in new car CO_2 (SMMT 2018). Switching from diesel accounts for a small proportion of this increase; the main culprit is a continued swing towards larger passenger cars, particularly Sports Utility Vehicles (SUV). Electric vehicles only account for 3 % of sales, with three out of four sold being plug-in hybrid electric vehicles (PHEVs), which have shown to perform little better in terms of carbon emissions than the most efficient conventional ICE vehicles in real world conditions (Plötz et al. 2018a, 2018b).

Despite well-established pockets of electrification (light and heavy rail) and slowly evolving ones (light duty vehicles and motorised two-wheelers), scenario exercises by fuel companies, international energy agencies, environmental NGOs and utility companies all come to uncannily similar conclusions about the transport sector – a lot of fossil fuel will still be burnt globally within the sector in 2050 and beyond (AEA Technology 2009; CCC 2015; IEA 2011, 2015; Köhler et al. 2009; OLEV 2013; Sims et al. 2014). Widespread electrification is proving to be a very slow process of continuous change and is likely to be too slow to contribute meaningfully to meeting ambitious climate change mitigation targets. Sprei (2018) argued that the largest disruptive potential lies in the combination of three major innovations of widespread electrification, shared mobility and automation. However, the author acknowledges that "technology and innovations alone will not be sufficient to create a new sustainable transportation system, regulations will also be necessary".

To accelerate the transition to low carbon transport system, the phasing out of the sale of new conventional petrol and diesel vehicles by a given date is one of a number of potentially 'disruptive' regulatory policies that have been announced over the past five years. Several countries and cities have committed to phasing out conventional vehicles between 2025 and 2040 (WorldAtlas 2018), with manufacturers also announcing targets (Reiter and Parkin 2019). A long awaited report by the UK Department for Transport (the 'Road to Zero' strategy, or R2Z), expected to address decarbonisation of the transport sector as a whole, turned out to focus on roads only, with the major emphasis on passenger cars (DfT 2018). This included an ambition for ultra-low emission vehicle (ULEV) sales of 50–70 % by 2030, and 40 % for vans, ahead of a ban on sales of diesel and petrol cars and vans by 2040. Criticism was immediate and widespread. Firstly, there remains ambiguity over the definition of an ULEV, leaving the door open for hybrid electric vehicle (HEV) sales after 2040.[1] Secondly, the 2040 target is weak by international standards, with many calling for this to be introduced a decade earlier (CCC 2018a; House of Commons 2018). Thirdly, the policies identified to achieve this are deemed by many to be inadequate. These include improvements to charging infrastructure, maintenance of grants for some ULEV purchases and potential reforms to vehicle tax. The ambition set for vehicle efficiency and fuel decarbonisation falls far short of the scientific evidence on what is required to meet carbon targets. With 60 % of UK surface transport's carbon emitted by the car fleet, the sector is pivotal to any post-Paris programme of action. Notwithstanding the most optimistic predictions of carbon intensity based on the new test cycle figures, and the recently agreed cuts in new car and van CO_2 by 2030 (-37.5 % and -31 % over 2021 levels for cars and vans respectively)[2], the mix of cars sold for the next decade or two will lock in fossil fuels for some time to come (Morgan 2019).

Overall, there is lack of robust analysis that examines the various targets and phase outs in terms of the key trade-offs in improving carbon emissions, air quality, and public health at various scales (national, subnational, city). There are also important issues around public acceptability, including how people buy cars, how cars need to be sold, accessed and utilised in order to accelerate turnover in the fleet. These need further investigation through the lens of 'disruption'. This paper therefore **aims to investigate transitions away from carbon-intensive car and van transport by exploring 'disruptive' rates of change in comparison with 'natural' rates of change**. The main objectives are:

- To represent and explore disruptive/discontinuous change in transport energy systems;
- To explore scenarios of disruptive and more incremental change in decarbonising car and van based transport in the UK;
- To assess how disruptive and/or continuous the scenarios may be for key stakeholders of the socio-technical system (who, when, reach and significance).

By doing so it explores what the impacts might be if the Government were more ambitious (reach and significance); how much 'disruption' is needed to meet ambitious carbon targets; and who (manufacturers and industry, users and civil society, and government itself) might be effected when.

Approach, methods and data

ANALYTICAL FRAMEWORK

We have used a socio-technical approach to organise policy options and map their effects on the transport-energy system. The starting point was Greg Unruh's Techno Institutional Complex framework, which has been used to explain the failed diffusion of 'carbon free technologies' (Unruh 2000, 2002). According to Unruh techno-institutional 'lock-in' is a persistent state that creates systemic market and policy barriers to technological alternatives and occurs through combined interactions among technological systems and governing institutions (Unruh 2000, 2002). Unruh distinguishes between transition stages as being either end-of-pipe (incremental), continuous (non-disruptive) or discontinuous (disruptive or radical). The original framework (Unruh and Carrillo-Hermosilla 2006) had two axes of organisation: *degree of disruption* (continuity → disruption) and *degree of lock-in* (developing → industrialised). In line with socio-technical studies (e.g. Smith et al. 2005; Yuan et al. 2012), we adapted the latter to *degree* or *level of coordination* so that the adapted framework maps policy scenarios by their *degree of disruption* (continuity → disruption) and the *level of coordination* (emergent transformation → purposive transition). As we will see later (Figure 5), the framework was considered as a tool for organizing policy analysis within the context of large transport-energy based-systems.

The levels of disruption and coordination may vary according to the actors involved or impacted on. For instance, high and wide ranging EV subsidies (as in Norway) may mean continuity for some actors (e.g. non-car owners, but also car owners) but potential disruption for others (e.g. vehicle manufacturers and

1. In the UK Ultra Low Emission Vehicle (ULEV) is the term used to describe any vehicle that: uses low carbon technologies; emits less than 75 g of CO_2/km from the tailpipe; and is capable of operating in zero tailpipe emission mode for a range of at least 10 miles (16.1 km).

2. The European Council agreed in late 2018 that from 2030 onwards-new cars will be allowed to emit on average 37.5 % less CO_2 and new vans will emit on average 31 % less CO_2 compared to 2021 levels. Between 2025 and 2029, both cars and vans will be required to emit 15 % less CO_2.

their supply chains, central government). Our analysis therefore distinguishes between four categories of actors:

1. Technology providers, industry and business (e.g. car manufacturers, leasing companies);
2. Consumers (largely owners and users of cars or vans);
3. Organizations and institutions in policy and planning (central government, local government);
4. Wider civil society (not everybody owns or uses a car or van).

MODELLING 'DISRUPTION' AND 'CONTINUITY' IN THE TRANSPORT-ENERGY SYSTEM

Disruption and continuity within the transport-energy system was modelled using an established modelling tool suitable for policy analysis, the Transport Energy and Air pollution Model for the UK (TEAM-UK). TEAM-UK is a disaggregated, bottom-up modelling framework of the British transport-energy-environment system, built around a set of exogenous scenarios of socio-economic, socio-technical and political developments. It integrates a transport demand simulation model, household car ownership model, consumer segmented vehicle choice model, vehicle fleet evolution model and vehicle and fuel life cycle emissions model in a single scenario modelling framework. The model projects transport demand and supply, for all passenger and freight modes of transport, and calculates the corresponding energy use, life cycle emissions and environmental impacts year-by-year up to 2100 (NB: the time horizon for this study was 2012 to 2050). To date, the underlying transport-energy-environment system modelling framework has been applied in a number of prospective scenario (Anable et al. 2012; Brand et al. 2019; Brand et al. 2017) and policy (Brand et al. 2013) modelling studies.

TEAM-UK represents an enhanced version of the UK Transport Carbon Model (Brand et al. 2012) – the main improvements include a wider range of outcome measures (air and noise pollution, land use change) and a more detailed passenger transport demand model. A detailed description is beyond the scope of this paper; and most of the methods have been published elsewhere (Brand 2016; Brand et al. 2017; Brand et al. 2012). Briefly, the transport demand model simulates passenger travel demand as a function of key travel indicators structured around data obtained from the UK National Travel Survey (Department for Transport 2016), including the average number of trips and average distance travelled per person per year. These were further disaggregated by seven main trip purposes (commuting, business, long distance leisure, local leisure, school/education, shopping, other), eight trip lengths (Under 1 mile, 1–2 miles, 2–5 miles, 5–10 miles, 10–25 miles, 25–50 miles, 50–100 miles, and More than 100 miles) and twelve modes of passenger transport (walk, bicycle, car/van driver, car/van passenger, motorcycle, local bus, coach, rail and underground, other private, taxi, domestic air, other public). International air travel is modelled separately as a function of income (GDP/capita), population and supply and policy costs. Freight demand is simulated as a function economic activity (GDP/capita) and population, with reference demand elasticities taken from a RAND Europe study (Dunkerley et al. 2014).

The vehicle fleet turnover model provides projections of how vehicle technologies evolve over time for 770 vehicle technology categories, including 283 car and 90 van (up to 7.5t) technologies such as increasingly efficient gasoline internal combustion vehicles (ICV), battery electric vehicles (BEV), plug-in hybrid electric vehicles (PHEV) and hydrogen (H_2) fuel cell electric vehicles (FCEV). The car fleet model is the most detailed, including market (private vs. fleet/company, three car sizes/segments) and consumer segmentation (four private and two fleet/company segments). New vehicle choice is modelled using a hybrid discrete choice and consumer segmentation model, as described in Brand et al. (2017). New car sales are a function of endogenously derived household car ownership and car scrappage, with the latter modelled as a function of average life expectancy via a S-shaped (modified Weibull) scrappage probability curve (Zachariadis et al. 2001). Based on existing age distributions, average car age was assumed to stay at 6.3 years, with 6.0 years for vans.[3] Total car ownership is modelled based on established methods (DfT 2013; Whelan 2007) taking into account household income, average vehicle costs, household location (urban, rural) and car ownership saturation rates for multiple car ownership.

The energy and emissions model calculates fuel and energy consumption as well as pollutant emissions for eight direct pollutants (carbon dioxide, CO_2, methane, CH_4, carbon monoxide, CO, sulphur dioxide, SO_2, nitrogen oxides, NO_X, non-methane volatile organic compounds, NMVOC and particulates, PM) arising from the operation of vehicles by using the established emissions factor method underlying COPERT (EEA 2012, 2017). This is most detailed for road vehicles, where emissions are based on average-speed emissions-curves for 'hot' emissions as well as excess emissions from 'cold starts' (ibid.). It allows modelling the combined effects of different fleet compositions, different sets of emission factors, traffic characteristics, cold starts, fuel quality, fuel blending (e.g. diesel/biodiesel blends) and driver behaviour.

Last but not least, TEAM-UK includes a life cycle inventory (LCI) model and an environmental impacts assessment (EIA) model based on a typical environmental life cycle assessment framework (ICO 2006). The life cycle inventory model calculates energy use and emissions (including primary energy and land use) for the manufacture, maintenance and disposal of vehicles; the construction, maintenance, and disposal of infrastructure; and the supply of energy (fuels). This adds 18 unregulated air pollutants and land use change indicators. The environmental impacts assessment model then provides an assessment of the damage caused by calculating impact indicators (e.g. global warming potential) and lower/upper bounds of external costs (e.g. damage costs to human health, social cost of carbon). Further details on methods and data for the LCI/EIA models are given in Brand (2016).

3. The UK car fleet age profile implied a 50 % scrappage probability was for cars or vans that were about 16 years old.

Table 1. Narratives and key assumptions for the alternative scenarios for phasing out 'conventional' fossil fuel cars and vans in the UK.

	Ban sale of non-ULEV cars and vans from	
ULEV def.	**2040**	**2030**
ICE ban	*ICE ban 2040 (RZ1):* Availability of new conventional petrol and diesel ICE cars and vans is drying up from 2035, with no ICE vehicle sold from 2040 onwards. No change in Reference (REF) assumption for the plug in vehicle grant or other incentives.	*ICE ban 2030 (RZ1a):* Availability of new conventional petrol and diesel ICE cars and vans is drying up from 2025, with no ICE vehicle sold from 2030 onwards. Modestly improved market conditions for EVs (consumer awareness, charging infrastructure, increased range of makes and models) from mid-2020s onwards.
ICE+HEV ban	*ICE+HEV ban 2040 (RZ2):* Availability of ICE and HEV cars and vans is drying up from 2035, with no ICE or HEV vehicle sold from 2040 onwards. Much improved market conditions for EVs incl. 'universal' consumer awareness by 2035, increased certainty of access for fleet operations (up to 80 %), higher battery capacities, charging rates and faster off-street parking from the late 2020s onwards.	*ICE+HEV ban 2030 (RZ2a):* Availability of ICE and HEV cars and vans is drying up from 2025, with no ICE or HEV vehicle sold from 2030 onwards. Much improved market conditions for EVs incl. 'universal' consumer awareness by 2025, increased and earlier certainty of access for fleet operations, higher battery capacities, charging rates and faster off-street parking from the mid-2020s onwards.
ICE+HEV +PHEV ban	*ICE+HEV+PHEV ban 2040 (RZ3):* Availability of ICE, HEV and PHEV cars and vans is drying up from 2035, with no ICE, HEV or PHEV vehicle sold from 2040 onwards. Much improved market conditions for EVs incl. 100 % consumer awareness and certainty of access for fleet operations by 2040, higher battery capacities, charging rates and faster off-street parking from the late 2020s onwards.	*ICE+HEV+PHEV ban 2030 (RZ3a):* Availability of ICE, HEV and PHEV cars and vans is drying up from 2025, with no ICE, HEV or PHEV vehicle sold from 2030 onwards. Much improved market conditions for EVs incl. 100 % consumer awareness and certainty of access for fleet operations by 2030, higher battery capacities, charging rates and faster off-street parking from the mid-2020s onwards.
Reference (comparison scenario)	*REF*: Projection of transport demand, supply, energy use and emissions as if there were no changes to existing transport and energy policy. No ban. Consumers increasingly shy away from diesels post 'Dieselgate' (Brand 2016). Existing UK plug-in vehicle grant (OLEV 2018) for cars, vans, taxis and motorcycles (up to £3,500 for cars, depending on how 'plugged-in' the vehicle is) to 'phase out' by the late 2020s. Consumer awareness of EVs increases to ~50 % by mid 2020s then levels out. Certainty of access to charging for fleet operations stays at 40 %. Private access to overnight charging level at 70 %. See Brand et al. (2017) for detailed assumptions of the Reference case.	

SCENARIO ANALYSIS: THE CASE OF THE BAN ON NEW CONVENTIONAL FOSSIL FUEL VEHICLES

TEAM-UK was applied in a UK case study to compare policy options and map their effects on the transport-energy system in terms of impacts on fleet evolution, energy use, carbon/air quality emissions and revenue streams under the framing of disruption outlined above. The starting point was the so-called 'Reference' scenario, which depicted existing policy and plans but *without* the proposed ban on new conventional fossil fuel cars and vans. Six alternative scenarios were then developed and quantified, each with a different policy ambition in terms of (a) target date and (b) definition of what constitutes an ULEV. We explored two target dates (2040 and 2030) and three ULEV definitions (ICE ban, ICE+HEV ban, ICE+HEV+PHEV ban), generating a total of seven policy scenarios as summarized in Table 1. The main assumptions for the Reference and alternative scenarios are described in Appendix A1. It is worth noting that the electricity generation mix for all scenarios follows central government projections (mainly natural gas, wind, nuclear, solar – with some CCS coal and gas after 2030), implying the carbon content of retail electricity (including transmission and distribution losses of about 7 %) is gradually decreasing from about 390 gCO_2/kWh in 2015 to 157 gCO_2/kWh and 127 gCO_2/kWh by 2030 and 2050 respectively.

Results and Discussion

FLEET TURNOVER AND ULEV UPTAKE

Without a ban or further policy action (i.e. the *Reference* case), ULEV cars and vans (= BEV and PHEV) increase their market share from approx. 2 % in 2018 to about 14 % by 2030, then levelling off (Figure 1, left).

In contrast, the ban scenarios suggest that petrol and diesel ICE cars and vans are gradually phased out of the market as the policy signal of the impending ban on conventional vehicles bears fruit. This happens, of course, at different rates and scales depending on the ambition of the ban and underlying policies. Firstly, in the ICE-only bans (that allow conventional HEVs to be sold beyond the ban date), the shift towards UL-

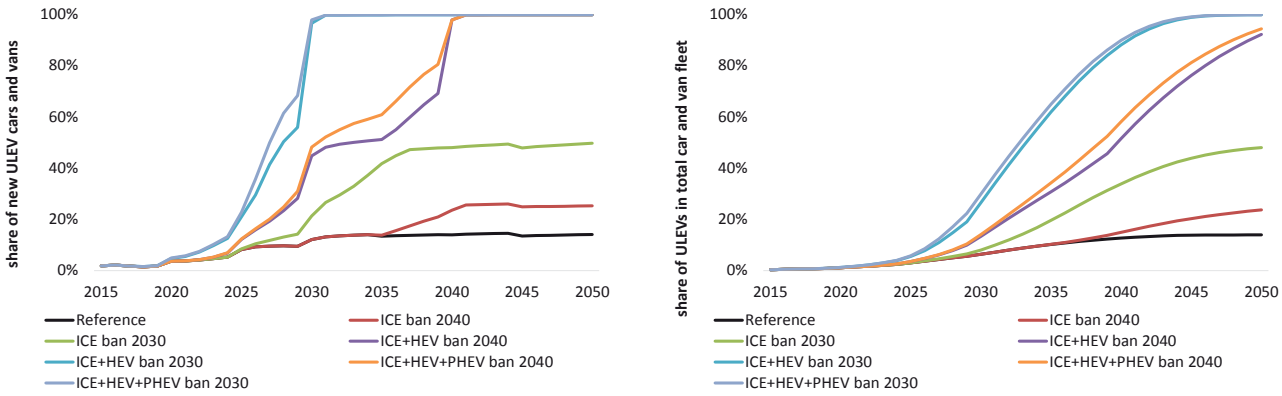

Figure 1. Scenario comparison of the share of sales (left) and total fleet (right) of ULEV cars and vans.

EVs is modest and driven by the 'fleet' and 'enthusiast' markets (Brand et al. 2017), with shares of new ULEVs up to 26 % (*ICE ban 2040*) and 49 % (*ICE ban 2030*) once the bans have been introduced. Secondly, in the more ambitious bans that include ICE and HEV vehicles, private, company and fleet buyers increasingly prefer ULEVs over conventional ICE and HEV vehicles, fuelled by a co-evolving EV market with increasing availability and performance of lower carbon vehicles and growing investment in home and fast recharging infrastructure. In the *ICE+HEV ban 2040*, ULEV take-up by the early adopter and mass markets and so-called 'user-choosers' (Brand et al. 2017) starting in the late 2020s mean that ULEV vehicle sales reach the 50 % mark by the early 2030s, with 100 % take-up by 2040 as expected by the policy. Moving the ban date forward to 2030 (*ICE+HEV ban 2030*) increases the rate and scale of the transition to plug-in vehicles, with nearly 50 % of sales being ULEV by 2027 and 100 % take-up by 2030. Thirdly, when also including PHEV in the bans the results do not change much from the ICE+HEV bans, which showed low take-up rates of PHEV in favour of BEVs. The main difference is that ULEV are taken up 1 or 2 years earlier than in the ICE+HEV scenarios. So, overall we would expect little change in the early 2020s but a profound shift in vehicle buyers' technology preferences and choices in the late 2020s (earlier ban) or late 2030s (later ban).

In terms of meeting the objectives of the UK Government's 'Road to Zero' (R2Z) strategy (DfT 2018), the results suggest that the R2Z 'mission' for all new cars and vans to be 'effectively zero emission' by 2040 – and the R2Z 'ambition' of 50 % new 'ULEV' by 2030 – would only be met by including HEVs in the ban.[4]

The continued sale of conventional ICE and HEV petrol and diesel vehicles – and relatively lower shares of ULEVs in the fleet – implies that there would still be a lot of fossil fuel cars and vans on the road in 2050, particularly in the ICE ban scenarios (Figure 1, right). As for diesels, we expect between zero (ICE+HEV ban 2030, ICE+HEV+PHEV ban 2030) and 4.0 million (ICE ban 2040) vehicles on the road in 2050. While this is significantly lower than the total fleet of 11.4 million diesel cars and vans in the Reference case, it suggests that an effective phasing out of fossil fuelled cars and vans by 2050 may only happen with earlier ban target dates and a stricter definition of what constitutes a ULEV (ICE+HEV 2030, ICE+HEV+PHEV 2030). This confirms other work, including by the Committee on Climate Change, which sums up the critique of most as follows:

> Leaving open the possibility of sales of conventional hybrids and very short range plug-in hybrids in 2040 and following years is inconsistent with the UK's climate change commitments. To meet the Government's stated goal of every car and van being zero emission in 2050, only pure battery electric vehicles and long range plug in hybrids can be sold after 2035. (CCC 2018a)

PROGRESS TOWARDS MEETING EMISSIONS TARGETS

Figure 2 (left) shows tailpipe (direct, at source) CO_2e emissions from UK cars and vans for the seven scenarios compared to the current (80 %) and potential Paris target (95 %) for 2050.[5] This clearly shows the 'R2Z' (*ICE ban 2040*) may neither hit the targets nor make the early gains needed for a 1.5°C trajectory, suggesting the strategy may achieve too little, too late.

Progress towards existing and future 1.5 °C targets across the range of bans was mixed – with the latter only met in the earlier and more stringent ban. The largest and earliest savings were in the *ICE+HEV* and *ICE+HEV+PHEV* bans by 2030. Specifically, the earlier ban that included ICE and HEV resulted in 20 % and 82 % reductions in tailpipe CO_2 emissions by 2030 and 2050 when compared to the 'R2Z' scenario (*ICE ban 2040*). Total reductions of this scenario against 1990 levels were 32 % (2030) and 93 % (2050), compared to 16 % (2030) and 37 % (2050) in the Reference case. The 2040 target scenarios reached similar reductions only in the second half of the assessment period.

Figure 2 (right) shows life cycle CO_2e emissions from UK cars and vans for the seven scenarios. This clearly shows that adding upstream and downstream CO_2e emissions from vehicle manufacture, maintenance & disposal and the supply of energy (fossil fuel production, electricity generation) basically shifts the emissions trajectories up by between 30 and 40 $MtCO_2$ p.a. This is largely due to *total* upstream and down-

4. The strategy sets an interim ambition for ultra-low emission vehicle sales (ULEVs) of 50–70 per cent by 2030, and 40 per cent for vans, ahead of a ban on diesel and petrol cars and vans by 2040.

5. Based on baseline 1990 emissions of 70.3 $MtCO_2$ for cars and 11.5 $MtCO_2$ for vans, i.e. a total of 81.8 $MtCO_2$. Assuming national targets were shared equally across the economy and the transport sector, the legislated -80 % and Paris 'near zero' -95 % targets were 16.4 $MtCO_2$ and 4.1 $MtCO_2$ respectively.

stream CO_2e emissions (vehicle and fuel LCA data based on Kay et al. 2013) remaining roughly constant over time as emissions from the generation and distribution of electricity replace those from fossil fuel production and distribution. As mentioned above the carbon content of retail electricity is gradually decreasing from about 390 gCO_2/kWh in 2015 to 157 gCO_2/kWh in 2030 and further to 127 gCO_2/kWh by 2050. While the increase in electricity use in the high electrification scenarios is significant (see also Figure 4), the decrease in the carbon content coupled with decreases in upstream emissions from fossil fuel production balance each other out. Further analysis showed that the combined upstream carbon emission from electricity generation and fossil fuel production decreased from 21.9 $MtCO_2e$ in 2015 to between 17.4 $MtCO_2e$ (all 2030 ban scenarios) and 18.4 $MtCO_2e$ (*Reference* and *ICE ban 2040*) by 2030. By 2050, this decreased further to between 10.9 $MtCO_2e$ (*ICE+HEV ban 2030*) and 12.8 $MtCO_2e$ (*ICE ban 2040*), which is lower than the 15.1 $MtCO_2e$ in the Reference case. So, upstream fossil fuel emissions were replaced by somewhat lower electricity generation emissions. It is worth noting that not all of upstream and downstream emissions are within the UK boundaries or accounts; therefore, a direct comparison with national climate change targets is inappropriate.

PROGRESS TOWARDS IMPROVING AIR QUALITY

The bans on the sale of conventional fossil fuel cars and vans explored here can accelerate reductions in air quality emissions in the medium to long term, but not the short term. Figure 3 (NO_X on left, $PM_{2.5}$ on right) clearly shows downward trends for all scenarios in the short term, largely due to lower emission ICE and HEV (and some plug-in) vehicles replacing older more polluting ones.

As expected, from the mid 2020s onwards tailpipe NO_X emissions decreased *more* in the 2030 scenarios (between 7 % and 26 % by 2030, and between 55 % and 100 % by 2050, when compared to the Reference case) than in the 2040 scenarios (between 0 % and 8 % by 2030, and between 34 % and 94 % by 2050). Similarly, tailpipe $PM_{2.5}$ emissions decreased more in the 2030 scenarios (between 10 % and 22 % reductions over baseline by 2030, and between 69 % and 100 % by 2050) than in the 2040 scenarios (between 0 % and 5 % by 2030, and between 52 % and 91 % by 2050). The R2Z (*ICE ban 2040*) only shows air pollution benefits from the late 2030s onwards. This suggests that in order to reduce the health burden of road traffic pollution faster, the earlier transformation to a cleaner ULEV vehicle fleet may be more effective than existing government strategy (R2Z, UK Air Quality Strategy) that implies breaching international AQ limits may continue well into the 2030s.

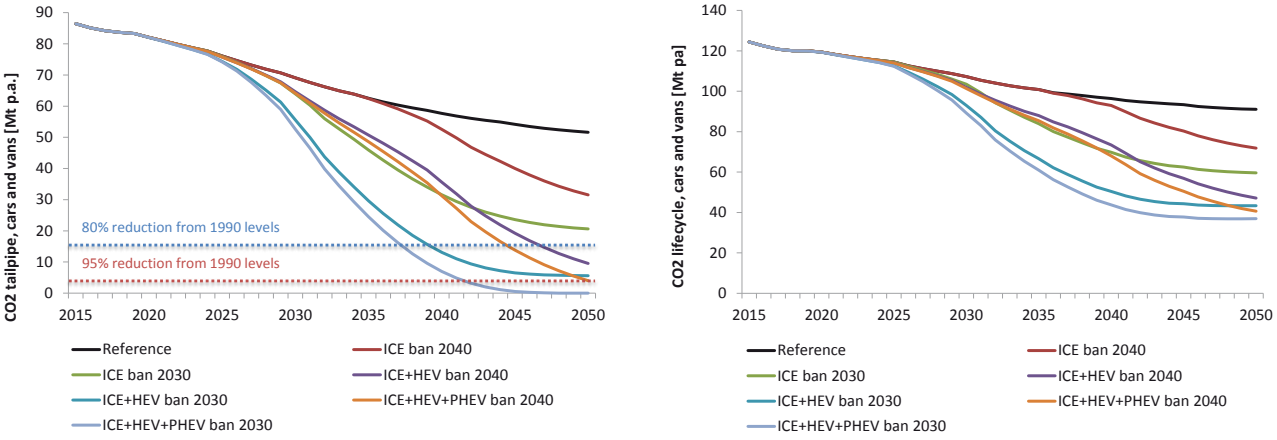

Figure 2. Scenario comparison of tailpipe (left) and life cycle (right) CO_2e emissions from cars and vans.

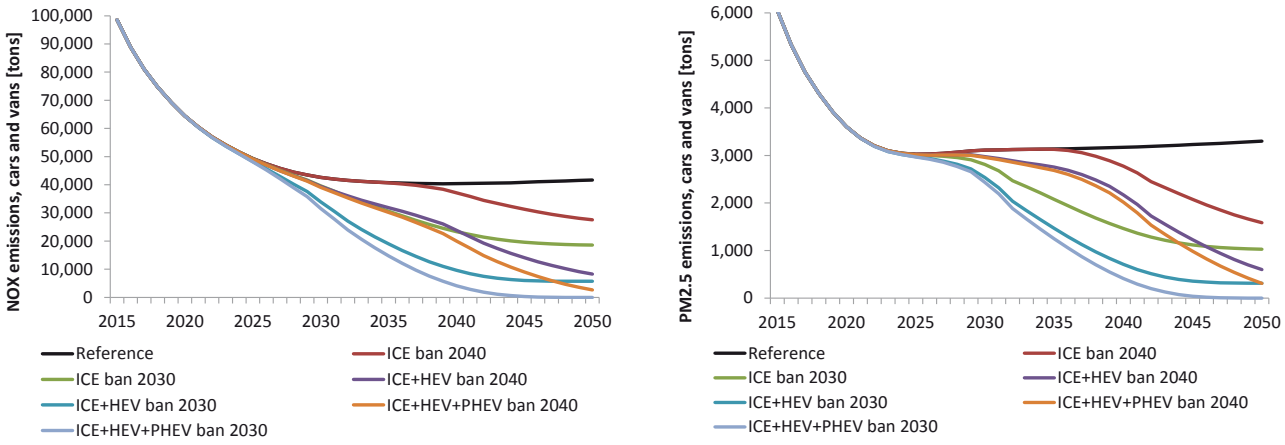

Figure 3. Scenario comparison of direct NO_x (left) and $PM_{2.5}$ (right) emissions from cars and vans.

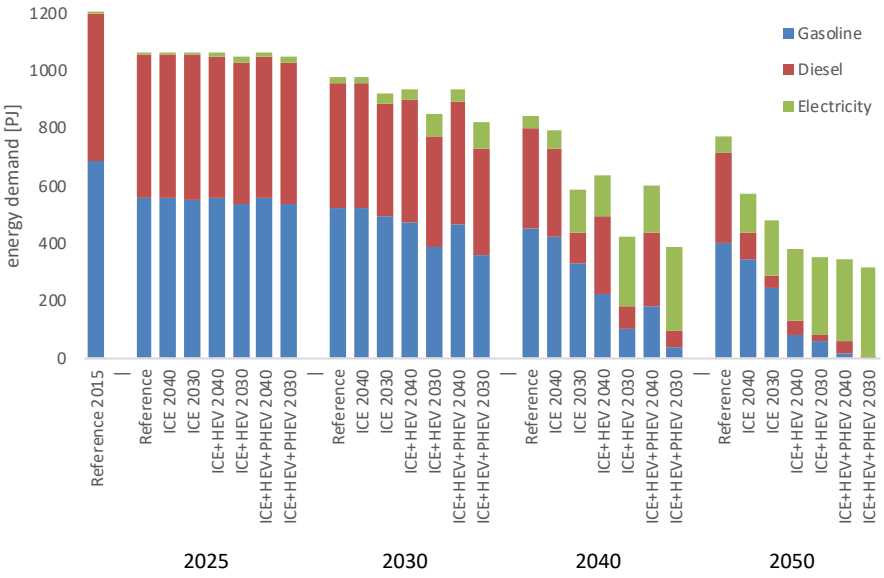

Figure 4. Transport energy demand from cars and vans (in PJ) for the main transport fuels.

CHANGES IN ENERGY DEMAND AND ROAD FUEL DUTY REVENUES

In the short term (until about 2025) all scenarios showed a gradual decrease in overall energy use, which is due to improvements in vehicle energy efficient outpacing increases in demand for car (+6 % between 2015 and 2025) and van (+16 %) travel (Figure 4). Demand for electricity was marginal except for the 2030 bans of hybrids and plug-in hybrids.

In the medium to longer term the modelling showed modest (2030) to large (2050) decreases in energy consumption due to the uptake of more energy efficient plug-in vehicles (Figure 4). Energy demand reductions and fuel switching away from fossil fuels was largest in the more stringent and earlier scenarios (*ICE+HEV ban 2030, ICE+HEV+PHEV ban 2030*), with energy demand from cars and vans (in PJ) decreasing by up to 74 % by 2050 when compared to 2015; this contrasts to a decrease of 36 % by 2050 in the Reference scenario. By 2050, fossil fuel demand decreases further from -40 % in the Reference case to -63 % (*ICE ban 2040*), -89 % (ICE+HEV ban 2040) and -100 % (ICE+HEV+PHEV ban 2030). By comparison, electricity demand grows steeply from a low base of only 0.5 PJ in 2015, particularly in the second half of the period. By 2050, electricity use accounted for the majority of energy use in the scenarios that phase out conventional ICE *and* HEV (between 247 PJ and 315 PJ, compared to 57 PJ in the Reference case). By contrast, fossil fuels still dominate energy use in 2050 in the less ambitious scenarios, including the R2Z case (*ICE ban 2040*).

In 2017, GBP 21.1 Billion were raised from cars and vans through road fuel duty, which was almost entirely from the duty on gasoline and diesel of GBP 0.58/litre (HM Treasury 2018), with electricity being duty and tax free. This road tax revenue stream would not change significantly in the short term across the scenarios. However, in the medium term to 2035 the modelling suggests that road tax revenues would fall sharply to about GBP 7.4 Billion p.a. (ICE+HEV ban 2030), and even lower to £6.1 Billion p.a. in the stringent *ICE+HEV+PHEV ban 2030* scenario. By 2050, this revenue stream would virtually be wiped out in all scenarios that ban conventional ICE and HEV cars and vans.

DISRUPTIVE OR CONTINUOUS CHANGE?

Legislated bans on the sale of new conventional fossil fuel vehicles will involve a purposive transition, by which we mean high levels of coordination and intention within the system rather than an emergent transformation. Of course, we may experience system shocks with potentially smaller reach or significance not just within system, also from outside the system. Yet, given the nature of legislation and providing a policy signal for future change we propose that the bans investigated here are elements of a purposive transition.

In terms of the types of change, the above results suggest that in the R2Z (*ICE ban 2040*) pathway the actors of the car and van transport and energy system are likely to undergo continuous rather than disruptive change. This is due to the relative slow and limited evolution of the fleet towards 'unconventional' low carbon fuels, continuation of fuel duty revenue streams well into the 2040s and little additional reductions in energy demand and air pollutant emissions. However, in the earlier (2030) and stricter (in ULEV terms) pathways we can expect some disruption for technology providers, industry and business, in particular vehicle manufacturers, global production networks, the maintenance/repair sector as well as the oil & gas industry. This has been mapped in Figure 5.

However, the stronger policy signal of a 2030 ban that includes hybrids would provide certainty to manufacturers to invest and innovate, backed up by much improved market conditions for EVs that go beyond the R2Z strategy, incl. increased consumer awareness through marketing and awareness campaigns, increased and earlier certainty of access for fleet operations, higher battery capacities, charging rates and faster off-street parking from the mid-2020s onwards. If the UK succeeded in phasing out conventional *and* hybrid EV cars and vans, the oil and gas industry would gradually lose a major demand sector at potentially disruptive rates of change in the medium term (2030 and beyond). At the same time, central government would lose fuel duty revenue streams worth Billions of pounds a year, unless fossil fuel duty is replaced with (a yet non-existent) electric fuel duty. While this has been recog-

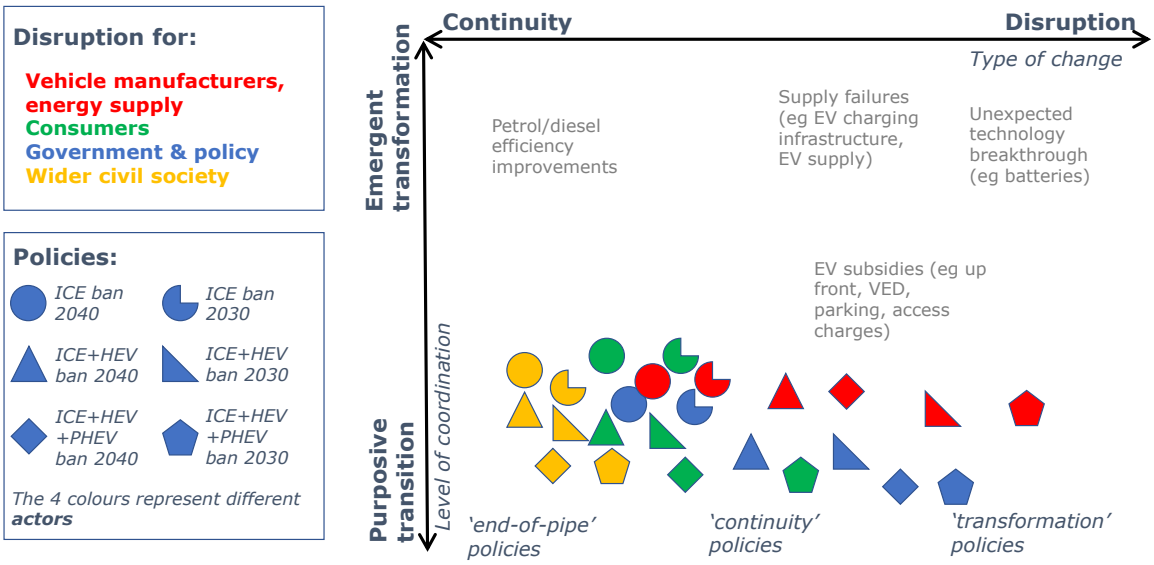

Figure 5. Mapping the fossil fuel ban policies onto our disruption and continuity framework.

nised as a potentially disruptive change (Howard et al. 2017), others argue that the loss of fuel duty does not matter economically (BVRLA 2019).

For other actors, particularly consumers and leasing companies, ULEVs represent continuous change as "a car is still a car" *in most respects* as we assume no significant advances in and uptake of shared mobility and automation[6], which are the other two major innovations that have disruptive potential (Sprei 2018) and are of emergent property. There will also be continuous change for local government (key actor in delivering charging infrastructure) and wider civil society, with air quality improvements expected to change gradually and in the second half of the assessment period, even in the most stringent scenarios. So, overall we found that the purposive transition of the proposed bans are less radical or disruptive as the system would be able, as a whole, adapt and change within the existing socio-technical system (Figure 5).

Conclusions

This paper set out to investigate transitions away from carbon-intensive car and van transport by exploring 'disruptive' rates of change in comparison with 'natural' rates of change in the transport-energy system. It used prospective scenario analysis and an established modelling tool to represent and explore 'disruptive' change in a transport energy system and to explore scenarios of disruptive and more incremental change in decarbonising car and van based transport in the UK.

The transport sector has 10 years to achieve 40 years-worth of carbon reductions if the latest warnings from the IPPC on the need for 'rapid and far reaching actions' are to be taken seriously. For cars and vans, the scenario modelling shows that existing policy ('Road to Zero': ICE ban by 2040) may neither hit the target nor make the early gains needed for a 1.5 °C trajectory, suggesting that the target for phasing out conventionally fuelled vehicles may be inadequate and not fit with our emissions targets. The 2040 date should be brought forward and linked to accelerated investment in networks and charging. The results of the earlier (2030) and more stringent (in ULEV definition terms) policies suggest that we may not necessarily need radical change in the car and van market – at least not disruptive for most actors in the socio-technical system.

Deep reductions in carbon emissions can be achieved by more ambitious but 'continuous' change, with a stronger policy signal of a 2030 ban that includes (plug-in) hybrids. This would provide certainty to manufacturers to invest and innovate, backed up by much improved market conditions for EVs. This would also bring multiple benefits (air pollution, as shown here, but also noise pollution and other co-benefits) for users and wider society as a whole. Government, however, would need to devise alternative revenue streams to the Billions it gets from fossil fuel duty. Equally, the manufacturing and maintenance industries would need to develop and adapt faster in the most ambitious cases. Yet we believe the more ambitious transition is feasible technically, economically and socially.

6. The two other so-called transport revolutions, Connected and Autonomous Vehicles and shared mobility, were considered but ultimately excluded from the analysis in order to keep the paper focussed on legislative bans and the phasing out of fossil fuel technology. Further work is underway to examine the combined effects of all three aspects.

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Appendix

A1 SCENARIO DESCRIPTIONS AND ASSUMPTIONS

The *Reference* scenario was modelled using TEAM-UK based on exogenous assumptions and projections of socio-demographic, economic, technological and (firm and committed) policy developments. Transport demand, supply, energy use and emissions were calibrated to UK national statistics for the base year of 2012. We obtained Special Licence Access to the National Travel Survey dataset (Department for Transport 2016) and used SPSS v23 to derive average trip rates, distance travelled and mode splits for the UK. Economic growth data up to 2017 were based on government figures. Future GDP/capita growth were assumed to average 1.35 % p.a. up to 2050. Transport demand projections were modelled based on no changes in trip patterns (i.e. trips and distance travelled per person p.a., and mode split) apart from lower commuting levels due to an ageing population, and average demand elasticities (of GDP/capita, population and generalized cost) for international air and freight transport (Dunkerley et al. 2014; Sims et al. 2014). Fuel price and retail electricity price projections were based on 2017 UK Government forecasts (BEIS 2017). Annual road tax and road fuel duties were assumed to remain constant at 2018 levels. For cars, we assumed a gradual decrease to zero by the late 2020s of the UK's existing 'plug-in vehicle grant', which will pay for 35 % of the purchase price for vehicles have CO_2 emissions of less than 50g/km and can travel at least 112 km (70 miles) without any CO_2 emissions at all, up to a maximum of £3,500. These are essentially BEVs. For PHEVs, the grant pays up to £2,500. For vans, the grant will pay for 20 % of the purchase price for vehicles that have CO_2 emissions of less than 75 g/km and can travel at least 16 km (10 miles) without any CO_2 emissions at all, up to a maximum of £8,000. These are essentially BEVs, apart from the Mitsubishi Outlander PHEV Commercial, a popular choice in the UK market.

Pre-tax vehicle purchase costs were kept constant over time for conventional ICE technologies and gradually decreased for advanced and future technologies, thus exogenously simulating improvements in production costs, economies of scale and market push by manufacturers. For example, average purchase

prices for BEV cars were assumed to decrease by 2.8 % pa from 2015 to 2020, by 1.6 % pa until 2030 and 0.6 % pa until 2050, based on projected BEV battery cost reductions (Nykvist et al. 2019).

The scenario set further assumed gradual improvements in specific fuel consumption and tailpipe CO_2 emissions per distance travelled (see Supplementary Materials in Brand et al. 2017). The rates of improvement were based on technological innovation driven entirely by market competition, not on policy or regulatory push. Fuel consumption and CO_2 improvement rates for future car vintages were assumed to be 1.5 % p.a. – a somewhat lower and more conservative rate than the average rate of 4 % p.a. based on test-cycle data for all new cars between 2008 and 2013. This is reasonable assumption as 'real world' improvements have been significantly lower, as shown by ICCT (ICCT 2014, 2016, 2017). Indirect emissions from fuel supply and vehicle manufacture, maintenance and scrappage were based on data from a UK-based review (Kay et al. 2013).

Alternative 'ban' scenarios

The alternative ban scenarios focus on regulatory and supply-side measures *against* conventional fossil fuel and *for* plug-in technologies. Depending on the policy ambition (target date, ULEV definition), these scenarios implied significant investment and repositioning towards ULEVs by the main vehicle manufactures with ultra-low emission vehicles (ULEVs) being available in all car segments (e.g. 'supermini', 'large family', 'crossover') and by all major brands by the target dates; 'universal' consumer awareness and acceptance of ULEV cars by the target dates driven by comprehensive awareness campaigns and the 'neighbour effect' (Mau et al. 2008). The regulatory 'sticks' and policy signals are balanced by the carrots of significant investment in recharging infrastructure (home charging, fast charging stations in and beyond the UK); improved certainty of access to charging for fleet operators; and reduced (perceived) recharging times. No improvement in so-called 'equivalent value support' (taxation, fuel duty) for ULEVs for both private and company/fleet buyers was assumed.