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How accelerating the electrification of the van sector in Great Britain can deliver faster CO_2 and NO_x reductions

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A B S T R A C T

As a major emission contributor with significant growth potential, the light goods vehicles (vans) play an important part in achieving net-zero. In 2020 the UK government committed to phasing out sales of new internal combustion engine (ICE) vans by 2030, but the impact of the policy and how far are we to decarbonize the entire van fleet by 2050 is unclear. This paper investigates the CO_2 and NO_x emission trends in the van sector in Great Britain under the 2030 ICE phase-out. ECCo model[1] is used to forecast the future van population by powertrain. The annual van mileage is estimated based on the van activity survey[2]. The instantaneous emission model PHEM, NAEI emissions inventory and remote sensing measurements are used to parameterize real-world driving emission factors of CO_2 and NO_x. Scenarios have been set out to assess the impact of enablers and barriers affecting the pace of emission reductions. Results suggest vans are on track to reach the tailpipe net-zero target by 2050 under all scenarios, and the speed of NO_x reduction is even faster. A rapid transition to battery electric vans in the early to mid-2020s will significantly lower CO_2, with associated estimated monetary benefits of £1.3 billion.

1. Introduction

The light goods vehicles (LGVs) or vans are a type of 4-wheel vehicle constructed for transporting goods and must have a gross weight of 3.5 tonnes or less (DfT, 2022a). In 2019[3] there were 4.1 million licensed vans in Great Britain, accounting for 10.7% of the total licensed vehicles (DfT, 2020d). In addition, vans have reached a record high of 55.5 billion vehicle miles in 2019, making up 16% of all motor vehicle traffic (DfT, 2020b). Alongside the fastest growth (DfT, 2020b; DfT, 2020d) of any motor vehicle in population (93%) and traffic (106.2%) over the last 25 years, vans were responsible for about 17.4% of greenhouse gas (GHG[4]) emissions (DfBEIS, 2021b) and 36.1% of NO_x emissions in 2019 (NAEI, 2021b) in the road traffic sector (UK figure, Northern Ireland included). To reduce the negative environmental impact of CO_2 emissions, the UK government has introduced a mixture of different policies and grants that could help encourage the wider use of electric vehicles (Hill et al., 2019; Wang et al., 2019). However, the take-up of electric vans has been slow in the van sector. 97.0% of the newly registered vans in Great Britain in 2019 were diesel-fuelled, while battery electric vans only represented 1.0%. By comparison, the battery electric passenger car market has seen continued growth, accounting for 7.9% of newly registered cars in 2019 (DfT, 2022b).

In 2020, to accelerate the transition to a low-carbon transport system, the government has brought forward the end of sales of new petrol and diesel cars and vans to 2030 (from 2040), with all new cars and vans being fully zero emission at the tailpipe from 2035 (HM Government, 2020). Many earlier studies have developed scenarios based on Great Britain's current policy measures and mechanisms, and estimated the

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1 http://www.element-energy.co.uk/sectors/low-carbon-transport/project-case-studies/

2 https://www.gov.uk/government/statistics/van-statistics-2019-to-2020

3 Year 2019 is regarded as the reference year in this paper to avoid the impact of Covid-19 on van population, van traffic, and van emissions.

4 Greenhouse gases (GHGs) are gases in the earth's atmosphere that trap heat and contribute to the global warming.

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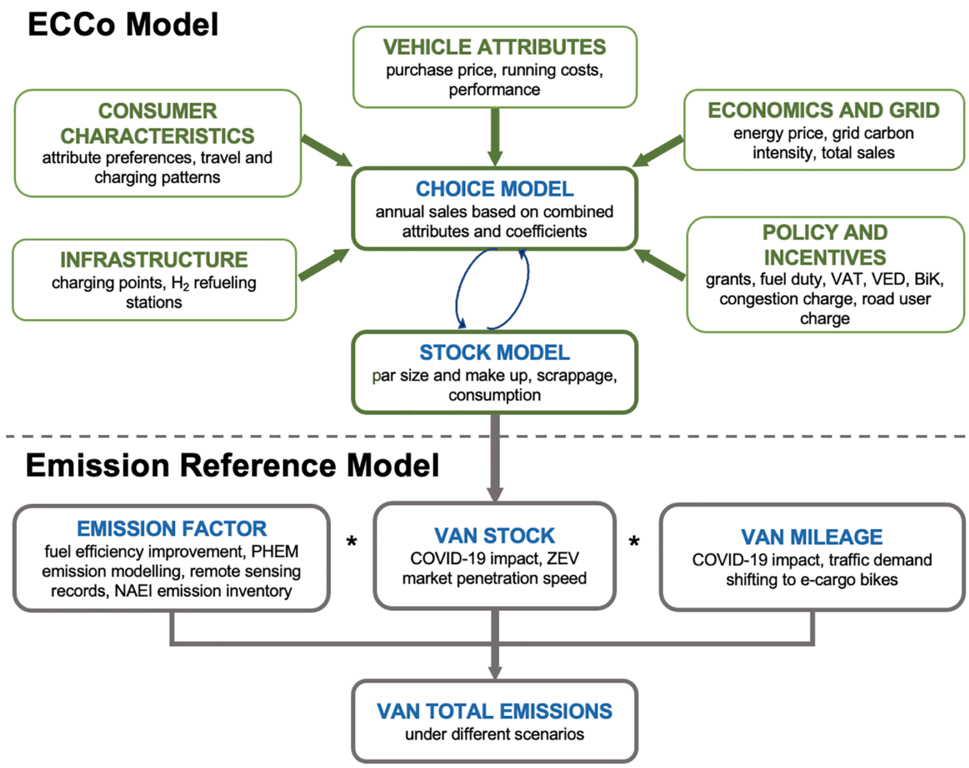

Fig. 1. Flow chart of ECCo model and emission reference model for the annual emission calculation, adapted from Pirie et al. (2020).

potential emission reduction (Hickman et al., 2012; Hill et al., 2019; Brand et al., 2020; Küfeoglu & Khah Kok Hong, 2020; Osei et al., 2021). However, first of all, these studies have predominantly limited their focus to passenger cars. Considering vans have a different fleet composition (DfT, 2022b) and driving pattern (Dun et al., 2015; Allen et al., 2018; SMMT, 2020) from passenger cars, and contribute significantly to CO_2 and NO_x emissions (DfBEIS, 2021b; NAEI, 2021b), it is considered both timely and important to have a separate and robust analysis of the van emission trend. Furthermore, these studies fail to provide scenarios that are applicable to the current policy i.e., whether the take-up trajectories are consistent with phasing out ICE[5] (internal combustion engine) vans by 2030 and reaching the net-zero target by 2050[6] is unclear.

This paper aims to explore the potential emissions impact of an ICE phase-out date for new van sales in Great Britain by 2030. The analysis is conducted by estimating detailed van CO_2 and NO_x emission trends from 2020 to 2040 in terms of different powertrains, class types[7] and primary usages. Van sales/stock numbers are directly derived from the Electric Car Consumer Model (ECCo) under a 2030 phase-out of ICEs (Pirie et al., 2020). An emission reference model is developed to estimate the total CO_2 and NO_x emissions of the van fleet, with average emission factors derived from the instantaneous emission model PHEM (Passenger car and Heavy duty vehicle Emission Model) (Hausberger & Rexeis, 2017; Yang et al., 2021) and the NAEI (2021a) emissions inventory respectively. Scenarios are then set out to analyse how varying the rate of uptake of large class III electric vans, accelerating the market penetration of battery electric vans, replacing vans with e-cargo bikes in urban areas and adapting NO_x emission factors to on-road remote sensing results would impact the possible emission mitigation level in the van sector. An economic impact analysis of CO_2 and NO_x emissions on public health and the environment under different scenarios is also conducted.

The rest of this paper is structured as follows. Section 2 describes methods developed to calculate the annual CO_2 and NO_x emissions in the van sector, the cumulative CO_2 emissions, and the total CO_2 emissions within a certain carbon budget. Section 3 introduces the baseline scenario and several alternative scenarios under phasing out ICE vans by 2030. Section 4 presents and analyses the results and Section 5 includes the main conclusions.

2. Methodology and data

This paper predicts the reduction potential of CO_2 and NO_x emissions from the van sector in Great Britain during 2020-2040 under different scenarios. In this section, the approach to predict the van population 2020-2040 (the baseline scenario) is described, along with the methods to estimate CO_2 and NO_x emissions produced. The evaluation of the five alternative scenarios is presented in Section 3.

2.1. Model structure

2.1.1. ECCo model

The van sales and van stock numbers in the baseline scenario are predicted by ECCo (Pirie et al., 2020). ECCo is a vehicle uptake model built by Element Energy[1] and is also used by the Department for Transport (DfT) for policy design. The central part of ECCo is a consumer choice model (see Fig. 1) that predicts the sales of different car and van

[5] The internal combustion engine (ICE) is any heat engine that obtains mechanical energy by burning chemical energy (fuel) in confined space (combustion chamber).

[6] In June 2019, the UK became the first major economy to commit to a 'Net-zero' emissions target by 2050.

[7] Vans can be further classified into three sub-categories by reference mass, where class I are vans not exceeding 1305kg, class II are those between 1305kg and 1760kg, and class III are those exceeding 1760kg (Annex I to Regulation (EC) No 715/2007).

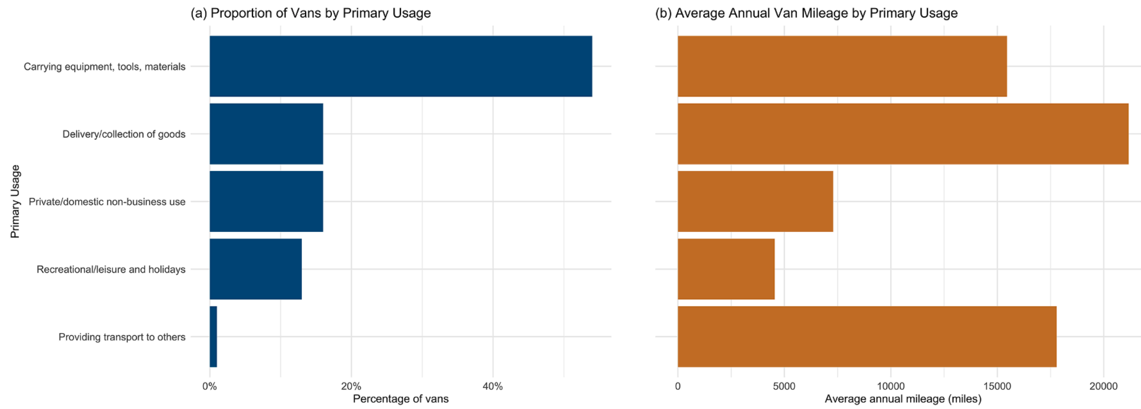

Fig. 2. (a) Proportion of vans [left] and (b) average annual van mileage (miles) [right] by primary use (DfT, 2020c).

powertrain technologies including ICE vehicles and all kinds of alternative fuel vehicles[8] (AFVs). It accounts for elements such as vehicle attributes (e.g., initial purchase cost, operation cost, vehicle performance), consumer characteristics, infrastructure (e.g., charging points), economics and grid, policy and incentives (e.g., grants, congestion charge) in the decision-making process. The sales figure generated by the choice model is then passed to a stock model to track vehicle usage through its lifetime. Pirie et al. (2020) used ECCo model to estimate the sales and stock of vans under two different scenarios, including a 2035 phase-out of ICEs scenario and an accelerated scenario that phases out ICEs in 2030. Relevant model inputs (e.g., subsidies and policies to meet the phase out goal) were developed for each of the scenarios and detailed van sales and van stock numbers were estimated.

2.1.2. Tailpipe emission calculation

- Annual emission calculation

This paper only estimates emissions of CO_2 and NO_x measured at the tailpipe and does not consider any upstream emissions produced (e.g., from electricity generation[9] or vehicle/battery manufacturers). The annual tailpipe CO_2 and NO_x emissions from vans are calculated by combining the number of vans on the road and traffic data with emission factors, and the emission reference model is shown as follows:

$$AE_y = \sum_{i,j,k,m} FAEF_{i,j,k,m,y} VP_{i,j,k,m,y} FAVKT_{i,j,k,m,y} \tag{1}$$

Where *AE* is the annual emissions of CO_2 or NO_x in a particular year; *FAEF* is the fleet average emission factor, *VP* is the number of vans on the road, *FAVKT* is the fleet average annual vehicle kilometres travelled; *i* is the Euro standard, *j* is the van class type, *k* is the fuel type, *m* is the primary use of the vehicle and *y* is the calendar year. It should be noted that as petrol ICE vans only represent 1.9% of newly registered vans and 3.1% of all licensed vans in 2021, and the petrol ICE vans on the road have seen an overall declining trend (DfT, 2022b), the petrol ICE fleet is combined with the diesel ICE fleet, and the emissions are not considered separately.

- Cumulative emission calculation

In addition to annual CO_2 emissions, the cumulative emissions are worth attention. Matthews et al. (2009) have noticed a linear relationship between temperature change and cumulative emissions. The UK Committee on Climate Change (CCC) (CCC, 2020a) also indicates that it is the cumulative total long-lived GHGs (e.g., CO_2 burnt by fossil fuels) that determine the peak global temperatures. The cumulative CO_2 emissions are calculated as follows:

$$CE = \sum_{y=2020}^{y=2040} AE_y \tag{2}$$

Where *CE* refers to the cumulative CO_2 emissions between 2020 and 2040.

- Emission calculation within a carbon budget

Another way to assess the carbon reduction speed is through the carbon budgets. To achieve the UK's long-term climate change objectives, carbon budgets were introduced in the Climate Change Act 2008[10], where a five-year, statutory cap on the total GHG emissions is set to assess whether the UK is on track towards the target of at least 100% reduction of 1990 levels (Net Zero) by 2050. The levels of these carbon budgets took account of the advice of the CCC[11]. The CCC (2020a) has published its latest 6th carbon budget report in 2020, and developed several scenarios to set out the expectations for carbon emissions across the sectors through the sixth five-year period (2033 to 2037). The UK's total GHG emissions in 2019 fell by 43.8% compared with 1990 whereas the absolute GHG emissions in the van sector was still 65.4% above the 1990 level (DfBEIS, 2021b). By calculating the contribution of the total five-year CO_2 emissions from vans to a certain carbon budget, one can assess the compatibility of the van sector emission trajectory with the net-zero target:

$$VC = \frac{\sum_{y=n}^{y=n+4} AE_y}{CB} \tag{3}$$

Where *VC* is the CO_2 emission contribution from the van sector during a certain carbon budget period, and *CB* is the corresponding

[8] Alternative fuel vehicles (AFVs) are propelled by something other than just a petrol or diesel ICE. AFVs include hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), battery electric vehicles (BEVs) and H_2 fuel cell vehicles. A HEV uses an internal combustion engine plus an electric motor. A PHEV is a hybrid electric vehicle that can be connected to a mains electricity supply to replenish the electric supply. A BEV is an electric vehicle that exclusively uses an electric motor, and the battery is charged by connecting to a mains electricity supply. A H_2 fuel cell vehicle is a type of electric vehicle which uses a fuel cell, instead of a battery, and fuel cells in vehicles generate electricity to power the motor, generally using oxygen from the air and compressed hydrogen.

[9] The UK's electricity is generated in a number of different ways (35.7% gas, 16.1% nuclear, 28.4% wind & solar and 12.6% other renewables in 2020) and it's moving towards renewable sources. (data from UK Energy in Brief 2021)

[10] https://www.legislation.gov.uk/ukpga/2008/27/contents

[11] https://www.theccc.org.uk/about/our-expertise/advice-on-reducing-the-uks-emissions/

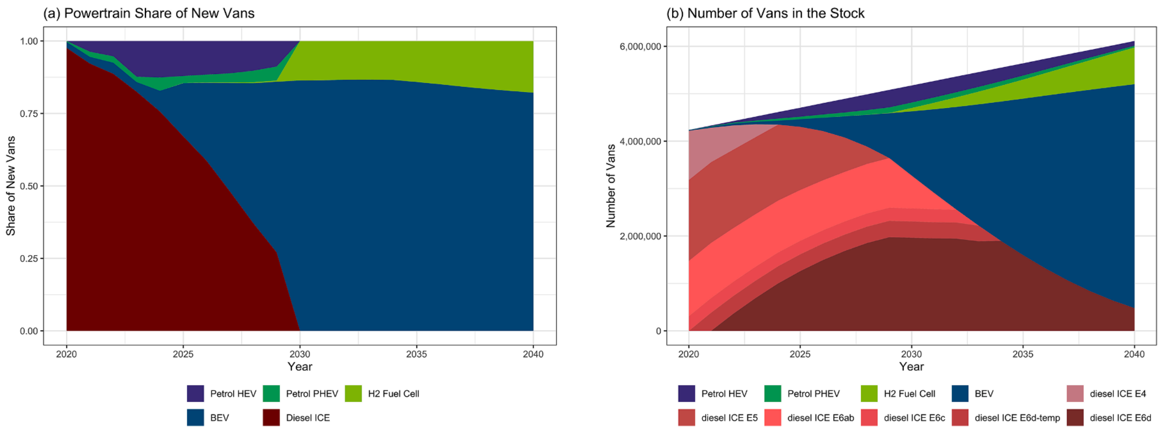

Fig. 3. (a) Share of new van sales [left]; and (b) number of vans in the stock [right] during 2020-2040, under the baseline scenario.

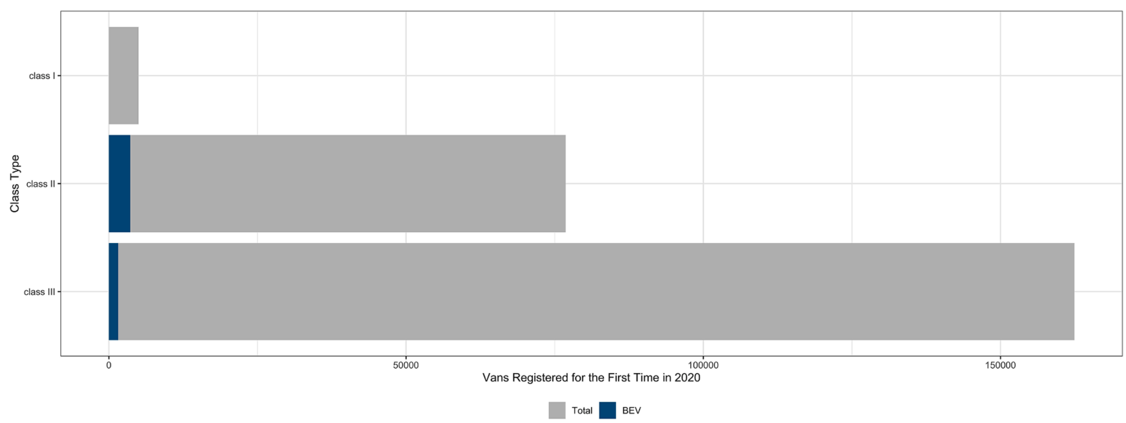

Fig. 4. Newly registered vans in 2020 in Great Britain (DfT, 2022b).

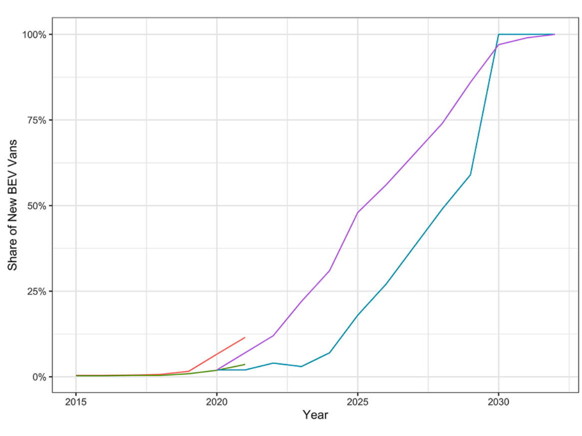

Fig. 5. Share of new BEV sales in car and van sector, and prediction of BL and RB scenario.

carbon budget.

2.2. Data

2.2.1. Projection of fleet composition

The impact of the coronavirus (COVID-19) pandemic on the van sales is only considered in 2020, because the rapid recovery of new van registrations in 2021 (DfT, 2022b). The fleet composition projection by Euro standard (see Table A1 in the Appendix) in the ICE van sector is based on historical and predicted new van sales in the baseline scenario, Euro standard implementation date of class II & class III vans and an average lifetime (age) of 13 years (Dun et al., 2015; SMMT, 2020). The fleet composition by class type (see Table A2 in the Appendix) within each Euro standard of ICE vans is estimated by annual sales of every generic model (DfT, 2022b) and their corresponding reference mass. It is assumed that Euro 6d-temp and Euro 6d ICE vans and all the AFVs (HEVs/PHEVs/BEVs/H_2 fuel cell vehicles) follow the class type composition of Euro 6c ICE vans.

This paper further classifies the van numbers based on van primary

Table 1
Proportion of new BEV sales in the BL and RB scenario in each year during 2020-2040.

Scenario	2020	2021	2022	2024	2026	2028	2030	2032 (and beyond)
BL	2%	2%	4%	7%	27%	49%	100%	100%
RB	2%	7%	12%	31%	56%	74%	97%	100%

Table 2
Substitution potential of e-cargo bikes in various studies.

Authors & Study Location & Project	Methodologies Description	Data Resource (s)	Substitution Potential*
Cairns & Sloman (2019) Great Britain Developing the evidence based on the contribution of the bicycle industry to Britain's industrial strategy	Predicting the substitution potential based on the percentage of all urban vehicle mileage constituted by delivery/service companies, and the potential of replacing delivery/service company trips by (e-)cargo bikes	DfT; LEFV-LOGIC project; CycleLogistics project	1.5-7.5% of mileage
Melo & Baptista (2017) Porto (Portugal) SusCity Project	Predicting the substitution potential based on using microscopic traffic simulation model to assess the network efficiency of using cargo cycles under different scenarios	AIMSUN (a microscopic traffic simulation model) developed for the city of Porto	Up to 10% of vans
Verlinghieri et al. (2021) London (Great Britain) Car-Free Megacities project	Predicting the substitution potential based on the percentage of all urban vehicle mileage constituted by delivery/service, and the percentage of van numbers that could be replaced by (e-)cargo bikes	An e-cargo bike logistics and pedicab company called Pedal Me	10% of mileage
van Amstel et al. (2018) Netherlands LEFV-LOGIC project	Predicting the substitution potential for every primary usage in the van sector based on the percentage of delivery vans in cities and the potential deployment of e-cargo bikes	Balm et al. (2018)	10%-15% of trips
Element Energy (2019) London (Great Britain) Report commissioned by TfL (Transport for London)	Predicting the substitution potential by scoring an area against the potential for cycle freight	Scoring	Up to 14% of vans
Wrighton & Reiter (2016) European cities CycleLogistics	Predicting the substitution potential for every primary usage in the van sector based on the number of trips that has the potential to shift to cargo bikes	NA	51% of trips
Gruber et al. (2013) Berlin (Germany) NA	Predicting the substitution potential based on the weight, volume, and shipment distance of e-cargo bikes	Pilot project in Berlin	19-48% of mileage

* While van mileage, van trips and van numbers are not directly comparable, the 2019-2020 van survey (DfT, 2020c) suggests that a certain share of vans travelling locally would have a much lower share of van total mileage.

use (shown in Fig. 2-a). The van activity survey (prior to covid-19 restrictions) carried out by DfT (2020c) suggests that vans are most frequently used for 'carrying equipment, tools and materials' (54%), followed by 'delivery or collection of goods' (16%) and 'private/domestic non-business use' (16%). Due to the increased use of vans for leisure journeys (Browne et al., 2014), a new primary usage of 'recreational/leisure and holidays' (13%) was introduced in the 2019-2020 survey. The proportions of vans for the top three usages in the 2019-2020 survey have all slightly decreased over the 11 years compared with the van survey conducted by DfT (2009) during 2008-2009. However, the introduction of the new primary usage also limits the comparability. Consequently, an assumption is made that the share of van numbers by primary usage during 2020-2040 will remain the same as in the 2019-2020 van survey (DfT, 2020c).

2.2.2. Average annual van mileage estimation

Though total distance travelled by van (DfT, 2020b) and van population (DfT, 2022b) saw significant growth between 1994 and 2019, the average mileage per van has remained broadly stable (DfT, 2020c). It is assumed that the annual mileage per van for every usage through 2020-2040 keeps at the same level as in the 2019-2020 van survey (DfT, 2020c) illustrated in Fig. 2-b, where vans used for 'delivery/collection of goods' have a much higher average mileage than other usages. In addition, though van statistics by DfT (2020c) indicates that van mileage of ultra-low emission vehicles[12] (ULEVs) only accounts for 54.2% of non-ULEV vans for the time being, the difference in van mileage between different powertrains is not considered in this paper.

The coronavirus (COVID-19) pandemic has a wide impact on the road traffic sector in 2020 in Great Britain. Car traffic decreased by 24.7% compared to the year 2019, while van traffic experienced a relatively smaller fall of 9.1% (DfT, 2021a). The volume of van traffic has returned to pre-covid level in 2021 based on DfT statistics (DfT, 2021b). As a result it is assumed in this paper that the average annual van mileage of every usage was 9.1% lower in 2020 compared with the 2019-2020 van survey (DfT, 2020c) and during 2021-2040 it remains the same as in Fig. 2-b.

2.2.3. Van CO_2 and NO_x emission factors

To improve fuel efficiency, the EU has set stricter fleet-wide CO_2 emission targets for new vans, with a 15% reduction from 2025 on and a 31% reduction from 2030 on (based on a 2021 baseline tested on the new WLTP[13] drive cycle). With the implementation of stricter regulations[14], it is expected the real-world fuel consumption of new conventional cars and vans is going to improve as well. Applicable technologies including downsizing, friction reduction and combustion improvement are going to reduce fuel consumption in compression-ignition diesel engines (National Research Council, 2015; Hu & Chen, 2016). Based on this the CO_2 and NO_x emission factors of all new diesel ICE vans are extrapolated using a compounded reduction of 4.0% per year from 2022 and 5.1% per year from 2025 to reach the goal of an overall reduction of 15% by 2025 and 31% by 2030.

- CO_2 emission factor

The instantaneous vehicle emission model PHEM (Hausberger & Rexeis, 2017) has proven to be able to accurately simulate the CO_2

[12] Vans that emit less than 75g of carbon dioxide (CO_2) from the tailpipe for every kilometre travelled.

[13] Worldwide Harmonised Light Vehicle Test Procedure (WLTP) is a chassis dynamometer test cycle for the determination of fuel consumption and pollutant emissions from light duty vehicles.

[14] https://ec.europa.eu/clima/policies/transport/vehicles/regulation_en (it is assumed the UK fleet emissions targets will remain aligned to the EU during the modelling period.)

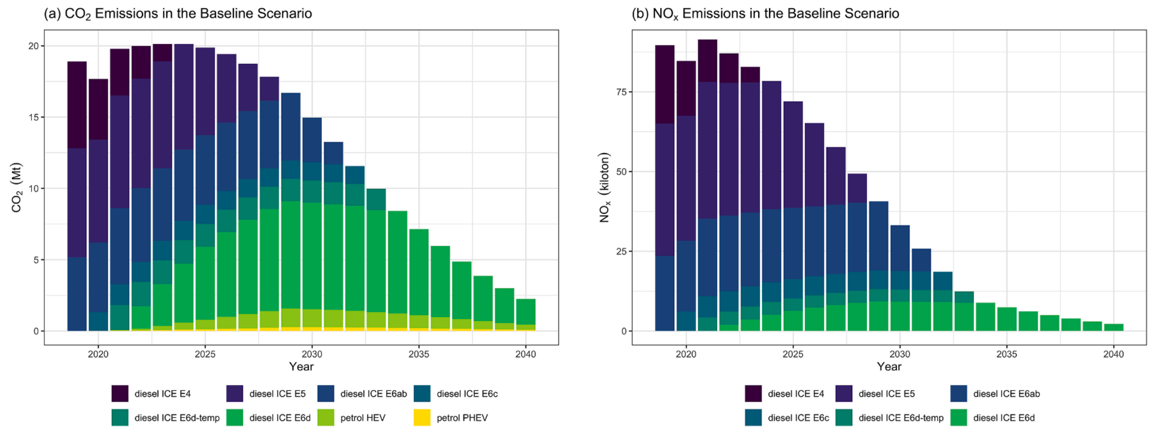

Fig. 6. (a) Annual CO_2 emission contribution by Euro standard and powertrain during 2020-2040 [left]; (b) annual NO_x emission contribution by Euro standard during 2020-2040 [right].

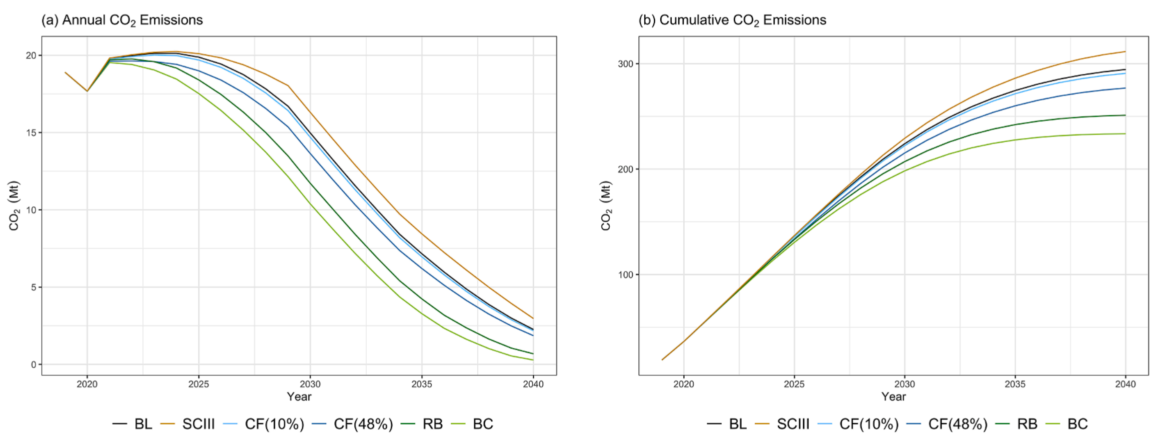

Fig. 7. (a) Annual CO_2 emissions [left]; (b) cumulative CO_2 emissions in Great Britain in 2040 [Right], under different scenarios.

Table 3
CO_2 emission contribution from the van sector for 4^{th}-6^{th} carbon budget under different scenarios*.

	BL	SCIII	CF (10%)	CF (48%)	RB	BC
4th carbon budget (2023 to 2027)	5.0%	5.1%	5.0%	4.8%	4.7%	4.4%
5th carbon budget (2028 to 2032)	4.3%	4.7%	4.2%	3.9%	3.4%	3.0%
6th carbon budget (2033 to 2037)	3.8%	4.4%	3.7%	3.3%	2.3%	1.8%

* (BL) Baseline scenario, (SCIII) Slow class III electric van uptake scenario, (RB) Rapid BEV penetration scenario, (CF) Cycle freight in urban areas scenario, (BC) Combined scenario: best case

emissions of diesel vans (Yang et al., 2021). PHEM can provide both second-by-second tailpipe emissions rates (g/s) based on the corresponding engine emission map as well as average emission factors (g/km) over a defined driving cycle. Average CO_2 emission factors of diesel ICE vans simulated by PHEM over the London Drive Cycle (LDC[15]) (Moody & Tate, 2017) are adopted in this paper (see Table A3 in the Appendix).

Petrol HEVs and petrol PHEVs vans are not included in the PHEM ADVANCE database so the CO_2 emission factors of these two powertrains are estimated based on the second-by-second CO_2 emissions of Euro 6a/b petrol ICE vans from PHEM over the LDC, and the known fuel consumption relationships among petrol ICE, petrol HEV and petrol PHEV vans (Fontaras et al., 2008; Orecchini et al., 2018; Matzer et al., 2019). Based on the findings from Fontaras et al. (2008) and Orecchini et al. (2018), it is assumed that the CO_2 emissions of a petrol HEV are 50% of a Euro 6a/b petrol ICE van when the speed is lower or equal to 20km/h. The benefit of hybrid powertrains gradually reduces as the average link/trip speed increases, and it is assumed that the emissions will linearly increase when the speed is between 20kn/h and 90 km/h, and beyond 90 km/h the CO_2 emissions are the same as petrol ICE vans. The average CO_2 emission of petrol HEVs over the whole LDC is regarded as the emission factor of petrol HEV (see Table A4 in the Appendix) in this paper. The CO_2 emission factor of a petrol PHEV is calculated using the following adapted equation (Matzer et al., 2019):

$$EF_{PHEV} = k_{EV} * \ EF_{EV} + (1 - k_{EV}) * EF_{HEV} \tag{4}$$

Where EF_{PHEV} is the weighted average emission factor of petrol PHEV vans, k_{EV} is the share of electrified kilometres of total kilometres driven of a PHEV, an estimate of 33.3% is used in this paper (Boston & Werthman, 2016). EF_{EV} is the emission factor of a petrol PHEV when it operates as an electric vehicle and it is considered to be zero. EF_{HEV} is the emission factor of a petrol PHEV when it's driven in hybrid mode, in this paper the emission factor of the petrol HEV is used. The detailed CO_2 emissions of petrol PHEVs by class type are provided in Table A4 in the Appendix.

[15] The London Drive cycle (LDC) a realistic on-road driving profile that is considered to be authentic and representative of real-world driving behaviour and vehicle emissions of the UK city traffic streets.

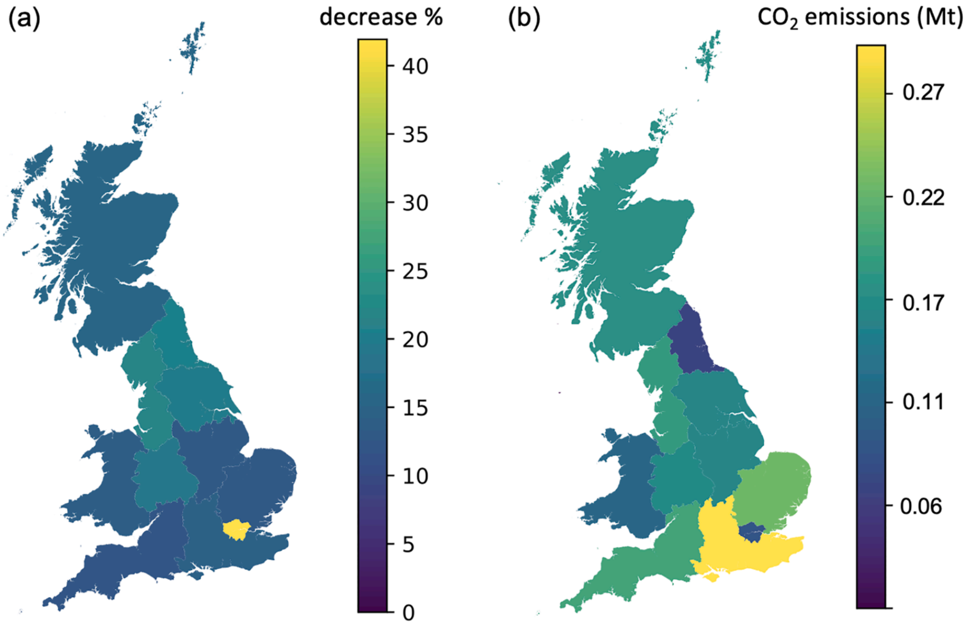

Fig. 8. (a) CO_2 emission reduction potential compared with the baseline scenario under a 48% of van-km substitution in each region and country in 2040 [left]; (b) absolute CO_2 emissions under a 48% of van-km substitution in each region and country in 2040 [right].

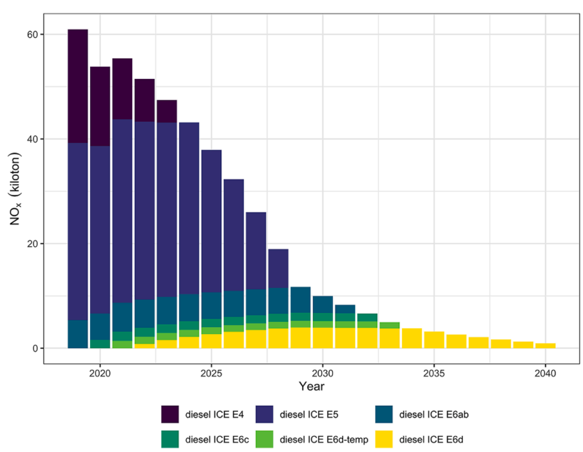

Fig. 9. NO_x emissions by Euro standard in the adapted NO_x emission factor (AEF) scenario.

Table 4
Total monetary savings of alternative scenarios compared with the Baseline (BL) scenario between 2020 and 2040.

Alternative scenario*	Central estimate of carbon value (million)	Carbon value sensitivity range (million) Low	High
SCIII	-£5,120	-£2,562	-£7,687
RB	£12,872	£6,440	£19,323
CF(10%)	£1,068	£534	£1,603
CF(48%)	£5,122	£2,562	£7,687
BC	£17,994	£9,002	£27,009
AEF	£4,125	£372	£15,807

* (SCIII) Slow class III electric van uptake scenario, (RB) Rapid BEV penetration scenario, (CF) Cycle freight in urban areas scenario, (BC) Combined scenario: best case, (AEF) Adapted NO_x emission factor scenario

Table 5
Summary of baseline and alternative scenarios from a societal perspective.

Scenarios	BEV (including H_2 fuel cell vehicle) share on the road	Emission reduction compared with 2019	Carbon value over the last 10 years compared with baseline scenario (million)
2030			
BL	27.6%	20.8%	NA
SCIII	21.4%	13.8%	-£1,440
RB	43.6%	38.1%	£4,697
CF(10%)	27.6%	22.3%	£503
CF(48%)	27.6%	27.9%	£2,413
BC	43.6%	45.1%	£7,111
2040			
BL	89.9%	88.1%	NA
SCIII	87.1%	84.3%	-£3,681
RB	97.1%	96.4%	£8,174
CF(10%)	89.9%	88.5%	£565
CF(48%)	89.9%	90.2%	£2,709
BC	97.1%	98.5%	£10,883

- NO_x emission factor

The NO_x emission factors of diesel ICE vans (provided in Table A3 in the Appendix) in the baseline scenario are directly adopted from NAEI (2021a), which uses the emission factor from the EMEP/EEA air pollutant emission inventory (EEA, 2019). The impact of adapting NO_x emission factors to remote sensing results that better account for the share and emission contribution from "high-emitting" vehicles with faulty or tampered emission controls are also explored in one of the alternative scenarios. In addition, as the NO_x emissions from petrol HEVs and petrol PHEVs are very low (Palmer, 2019), they are not considered in this paper.

3. Scenario design

In this section, one baseline and several alternative scenarios have been designed to assess the impact of some enablers and barriers affecting the effectiveness of CO_2 and NO_x emission reduction pace of vans. The brief narrative and key assumption of each scenario are stated as follows:

3.1. Baseline scenario (BL)

The detailed van sales and van stock numbers (see Table A5 in the Appendix) of a 2030 ICEs (including HEVs/PHEVs) phase-out in Pirie et al. (2020)'s research have been adopted in the baseline scenario. It should be noted that the UK government would allow PHEVs/HEVs to be eligible for new registrations until 2035, which is 5 years behind the assumption in the baseline scenario, but we consider the impact to be small. It is expected that the initial purchase price of a BEV is no more than a conventional vehicle by 2030 (CCC, 2020a), as a result many customers would skip the hybrid step and go straight to all-electric vehicles. Fig. 3 presents the predicted total van sales share and van stock number of different powertrains and Euro standards under the baseline scenario of phasing out ICEs (including HEVs/PHEVs) in 2030. A rapid increase in the BEV transition is only observed since the mid-2020s, as the actual share of BEV sales is still very low for the time being (3.6% in 2021 (DfT, 2022b)). There is a forced uptake of BEVs during 2028-2030 to meet the 2030 ICE phase out goal. The sales of H_2 fuel cell vans start to grow in 2030 to satisfy the demand of van users who have a higher daily mileage requirement (i.e., inter-urban highway driving). The petrol HEV and PHEV uptakes remain low, peaking at 12.6% and 4.6% respectively in 2024 and declining to 0.0% in 2030. It is estimated that there are 5.5 million zero emission vans (including BEVs and H_2 fuel cell vehicles) on the road in 2040 in the van sector, accounting for 89.9% of the whole fleet.

3.2. Slow class III electric van uptake scenario (SCIII)

Large vans are dominating the van market (SMMT, 2019), however the take-up of large electric vans has fallen far short of the level required to reach the 'phasing out ICE vans by 2030' goal (CCC, 2020b). Vehicle statistics from DfT (2022b) shows that class III vans accounted for 66.5% of newly registered vans in 2020 in Great Britain, while the electric class III vans only make up about 30.2% of total new BEV sales (see Fig. 4). The limited supply of large electric vans and the outright purchase cost are two main barriers acting against the mass adoption of class III electric vans (Greater London Authority, 2019). In the near future, the transition to BEVs may be limited to smaller class II vans.

This scenario has been designed to project a 50% slower electrification transition of class III electric vans. During 2020-2029, 50% of the newly registered class III vans that should have been electric (H_2 fuel cell vans also included) are still considered to be powered by diesel. It should be noted that in this scenario the total number of class III van sales during 2020-2029 is the same as the baseline scenario, only the fleet composition by powertrain technology changes.

3.3. Rapid BEV penetration scenario (RB)

The BEV uptake prediction in research literature has largely proven to be too pessimistic when compared with actual sales figures as they become available. For example, the central scenario in CCC (2020a)'s 6^{th} carbon budget report estimates that the share of BEVs in new car sales in 2021 would reach 7%, whereas in reality BEVs accounted for 11% of new car sales in 2021. ECCo model (Pirie et al., 2020) in the baseline scenario predicts 2% of the newly registered vans are zero emission in 2021, however in reality BEVs already accounted for 3.6% of the new van sales (DfT, 2022b). The share of BEV sales of passenger cars has already seen a significant increase between 2019 and 2022 (see Fig. 5), it is suggested that the vans might follow the BEV uptake speed in the car sector and have a rapid transition to BEVs in the early 2020s.

Market penetration of BEVs for cars under the central scenario in CCC (2020a)'s 6th carbon budget report has been adopted to represent a rapid transition of BEVs in the van sector (rapid BEV penetration scenario). In the rapid BEV penetration (RB) scenario, the BEV sales share starts to increase sharply in the early-2020s, making up 48% of new car sales in 2025 and 97% in 2030, and reaching 100% from 2032 onwards, whereas in the baseline (BL) scenario, the market penetration rate of BEVs (H_2 fuel cell vehicles included) does not see a significant increase until the mid-2020s, yet reaches 100% in 2030 (see Table 1).

3.4. Cycle freight in urban areas scenario (CF)

Urban van freight is estimated to represent 14.6% of the total urban traffic in 2019 in Great Britain (DfT, 2021b) and it contributes significantly to emissions/congestion in cities (Browne et al., 2012). E-cargo bikes are a potential technical solution to reduce urban freight transport's negative environmental and social impact (Narayanan and Antoniou, 2022; Philips et al., 2022). They are suitable for delivering small parcels in contained areas, such as in densely populated areas or central business districts (Verlinghieri et al., 2021). More importantly, they are zero emissions and take up less public space. Many studies have suggested the great potential of using e-cargo bikes to carry out urban commercial trips (see Table 2).

In this scenario a lower bound of 10% of total urban van-km (Verlinghieri et al., 2021) and an upper bound of 48% of total urban van-km (Gruber et al., 2013) have been adopted to estimate the potential emission reduction of replacing vans with e-cargo bikes. The urban roads[16] in each region and country in Great Britain (DfT, 2021b) are considered to meet the criteria to encourage cycle logistics. Firstly, annual CO_2 emissions in Great Britain are distributed to each region and country based on its corresponding van traffic share (DfT, 2021b). Then a 10% substitution potential or a 48% substitution potential is assigned to the urban roads in each region and country to account for the impact of replacing vans with e-cargo bikes. The van mileage share by region and country, and the proportion of van mileage driven on urban roads in each region and country are considered to be stable during 2020-2040, and the figures in 2019 are used and stated in Table A6 in the Appendix. A gradual (linear) growth of the van-km share in urban areas of e-cargo bikes is assumed, starting from 0% in 2020 up to 10% and 48% in 2040.

3.5. Combined scenario: best case (BC)

A best-case scenario has been designed to represent the situation of combining all the advantages of the previous scenarios: a rapid BEV penetration (RB scenario) and an encouragement of e-cargo bikes (CF scenario). In the BC scenario, the BEV sales share starts to increase sharply in the early-2020s, making up 48% of new car sales in 2025 and 97% in 2030, and reaching 100% from 2032 onwards. In addition, urban van traffic in each region and country will experience a gradual (linear) substitution of e-cargo bikes, starting from 0% in 2020 up to 48% in 2040.

3.6. Adapted NO_x emission factor scenario (AEF)

NO_x emission factors in the baseline scenario are directly adopted from NAEI (2021b), which shows little improvement between Euro 5 and Euro 6a/b/c vans (see Table A3 in the Appendix). However, studies have indicated that since the implementation of the much more stringent Euro 6a/b emission standard, then Euro 6d-temp and 6d, the real-world van NO_x emissions have decreased significantly (Chen et al., 2020; Ghaffarpasand et al., 2020; Yang et al., 2022). To analyse whether a lower NO_x emission factor is the breaking point in reducing total NO_x emissions, the NO_x emission factors from remote sensing measurements

[16] Urban roads: major and minor roads within an urban area with a population of 10,000 or more. These are based on 2011 Census definition of urban settlements.

captured in Great Britain during 2012-2019 (Yang et al., 2022) are used to parameterize the NO_x emissions of diesel ICE vans in this scenario.

Remote sensing systems only report the fuel-specific NO_x emissions (g/kg), and the distance-specific NO_x emissions (g/km) are generated based on the equation and parameters provided by Davison et al. (2020). The distribution of NO_x emissions is skewed-right and follows the Gumbel distribution (Rushton et al., 2021; Yang et al., 2022), therefore the location parameter of the fitted Gumbel distribution is used to represent the NO_x emission value of the normally behaving vehicles in a fleet. The remote sensing dataset does not include measurements from Euro 6c, Euro 6d-temp and Euro 6d diesel ICE vans, so the simulated average NO_x emission factors from PHEM over the LDC are used. However, the input data of Euro 6d-temp and Euro 6d vans in PHEM (version 13.0.3.21) are not from neither chassis dyno tests or portable emissions measurement system (PEMS) tests, but only a representation of the emission standard. As a result, the emission factors simulated by PHEM are multiplied with a conformity factor of 2.1 for Euro 6d-temp and 1.5 for Euro 6d for real-driving emissions (RDE)[17]. The detailed NO_x emissions of diesel ICE vans adopted in this scenario are provided in Table A3 in the Appendix.

4. Results and discussions

4.1. Baseline scenario results

The predicted trend of tail-pipe CO_2 emissions from vans in Great Britain under the baseline scenario is illustrated in Fig. 6-a. Year 2019 is used as the reference year because the van traffic and van sales in 2020 was heavily impacted by Covid-19 and therefore emissions in 2020 cannot represent the normal level at present. The total CO_2 emissions peak at 20.1 million tonnes (Mt) in 2024, and are then forecast to decrease. By 2040 the CO_2 emissions are only 11.9% of the 2019 level. Based on this pace of reduction, it is estimated the tailpipe net-zero target in the van sector will be reached by 2050. Fig. 6-a also shows the overall CO_2 emission contribution by powertrain and Euro standard. Diesel ICE Euro 5 vans have the largest share of CO_2 emissions from 2020 (40.4%) to 2025 (30.9%) and following that, diesel ICE Euro 6d vans contribute the most (from 30.5% in 2026 to 80.6% in 2040). The annual CO_2 emissions from HEVs & PHEVs are relatively low, peaking in 2040 at 19.4% while the absolute emissions are already very low. Küfeoglu & Khah Kok Hong (2020) argue that changing the driving behaviour of HEVs/PHEVs can impact the reduction of GHG emission reduction pace but we consider the impact in the van sector to be small. Increasing the fuel efficiency of diesel ICE Euro 6d vans and scrapping the Euro 5 diesel vans are two priorities to reduce CO_2 emissions.

Fig. 6-b shows the NO_x emission trajectory of the van sector in the baseline scenario. NO_x emissions peak at 91.3 kilotons in 2022 and then have a rapid decline. In 2040 the NO_x emissions would reach a reduction of 97.5% compared with the 2019 level. Euro 5 is contributing the biggest part of NO_x emissions from 2020 to 2026, mainly because diesel ICE Euro 5 vehicles are the most polluting vans (Chen & Borken-Kleefeld, 2014; ICCT, 2019). The contribution of NO_x made by Euro 6d vans is relatively low compared with its CO_2 contribution, as there has been significant improvement in NO_x exhaust aftertreatment technologies. Therefore, to reduce the impact of NO_x emissions on public health and the environment, it is recommended to replace the old Euro 5 diesel vans as soon as possible. Policies such as Low Emission, Ultra-Low Emission, Clean Air and Zero Emission Zones (Defra, 2018; DfT, 2020a) are aimed at accelerating the transition and use of cleaner vehicles in sensitive areas, with benefits extending over the wider transport area. In addition, emission contribution by primary usage is also analysed. The primary usage which accounted for the greatest proportion of CO_2 and NO_x emissions is 'carrying equipment, tools and materials' (61.1%), followed by 'delivery/collection of goods' (24.4%) and 'private/domestic non-business use' (8.3%).

4.2. Alternative scenario results

Fig. 7-a demonstrates the annual CO_2 emissions in the van sector during 2020-2040 under four alternative scenarios, compared with the baseline scenario. For the SCIII scenario, in 2040 the total CO_2 emissions from the van sector are 3.0 Mt. The result indicates that a 50% slower transition to class III BEVs would increase the CO_2 emissions by 31.5% in 2040 compared with the baseline scenario. Results in the CF scenario have indicated that a 10% of urban van-km substitution potential of e-cargo bikes would decrease the total CO_2 emissions in Great Britain by 3.7% in 2040, while substituting 48% of urban van-km would decrease the total CO_2 emissions by 17.8% in 2040 compared with the baseline scenario. A rapid transition to zero emission vans (RB scenario) appears to be a more effective route to lowering emissions, in 2040 the total CO_2 emissions from the van sector are only 0.7 Mt, a reduction of 69.7% compared with the baseline scenario. As for the best case (BC scenario) that combines the advantages of both replacing vans with e-cargo bikes and a rapid electrification of the van fleet in the early 2020s, the total CO_2 emissions from the van sector are only 0.3 Mt, a reduction of 87.5% is achieved compared with the baseline scenario.

Fig. 7-b is the cumulative CO_2 emissions of baseline and four alternative scenarios during 2020-2040. Compared with the BL scenario, cumulative CO_2 emissions in the SCIII scenario are 17.0 Mt higher in 2040. When 10% of van-km in urban areas is substituted by e-cargo bikes (CF scenario), a cumulative emission reduction of 3.7 $MtCO_2$ is reached in 2040, while a 48% van-km substitution represents 17.6 $MtCO_2$ cumulative emission reduction in 2040. Great Britain could reach a cumulative emission reduction of 43.4 $MtCO_2$ in 2040 in the case of the RB scenario. The difference in cumulative CO_2 emissions between the BL and the BC scenarios after 20 years is approximately 61.0 Mt, which is equivalent to 13.4% of the total GHG emissions in Great Britain in 2019.

Table 3 summarizes the GHG emission contribution of the van sector under different scenarios for the 4th-6th carbon budget. The results have shown that the GHG contribution from the van sector would decrease during the 4th-6th carbon budget if the government is consistent with its 2030 ICE phase-out plan. The gap between the four alternative scenarios and the baseline (BL) scenario has been widened over time, indicating any policy implemented or technology improvement will take time to produce a noticeable effect. Among all the alternative scenarios, the RB scenario would ease the heavy burden of mitigating the total GHG emissions, especially during the 6th carbon budget period, where the emission contribution from the van sector is only 2.3% of the total Carbon Budget. The BC scenario combining all the advantages of CF and RB scenario is found to account for only 1.8% of the total carbon budget over the 6th Carbon Budget period.

A detailed analysis of the CO_2 reduction potential by region and country in the CF scenario is presented in Fig. 8. Fig. 8-a shows the reduction percentage of CO_2 compared with the baseline scenario under a potential 48% of van-km in urban areas delivered by e-cargo bikes. London is considered to have the greatest potential to reduce CO_2 by encouraging e-cargo bikes, because 87.3% of its traffic occurs on urban roads. North West, North East, Yorkshire and the Humber, and West Midlands are also considered to be suitable to encourage cycle freight. Fig. 8-b shows the absolute CO_2 emissions by region in 2040 if 48% of the urban van traffic is replaced by e-cargo bikes, where the South East has the highest emissions (0.3 $MtCO_2$) among all the regions and countries, followed by East of England and South West.

[17] COMMISSION REGULATION (EU) 2017/1151

AEF scenario explores how adapting NO_x emission factors to remote sensing results could influence the NO_x emissions reduction pace in the van sector. Compared with the baseline scenario (Fig. 6-b), the NO_x emissions in the AEF scenario (Fig. 9) have a faster decreasing speed, reaching a reduction of 98.4% in 2040 concerning the 2019 level. The main difference between these two scenarios is the emission contribution made by Euro 6a/b and Euro 6d diesel ICE vans, where the emission factor from the baseline (BL) scenario (NAEI emission factor) is much higher than in the AEF scenario (remote sensing emission factor). In both BL and AEF scenarios, diesel ICE Euro 5 vans contribute a significant amount to the total NO_x emissions.

4.4. Economic impact analysis

Incorporating the monetary impact on changes of CO_2 and NO_x emissions resulting from alternative scenarios ensures a proper policy appraisal. For an appraisal of the change of CO_2 emissions, the 'carbon value' is used as the road transport sector is a non-traded sector (DfBEIS, 2021c). Carbon values represent the monetary value per tonne of carbon dioxide equivalent (£/tCO_2e), and the carbon values between 2020 and 2040 (in 2020 prices) used in this paper were developed by DfBEIS (2021d) and are listed in Table A7 in the Appendix. An example of the total benefits of CO_2 reduction in the RB scenario compared with the BL scenario is given in Table A8 in the Appendix. Furthermore, the external cost of changes in NO_x emissions is appraised using the 'damage cost' approach, which has been commonly used in the transport policy appraisal (Brand, 2016; Lott et al., 2017). Damage costs represent the monetary impact values per tonne of emission, including the impact of air pollutants on human health, productivity, wellbeing and the environment (Defra, 2021). The NO_x damage cost values for road transport sector used in this paper were developed by Ricardo (2020), and are listed in Table A7 in the Appendix. The total monetary impact of the change in NO_x emissions from the van sector is calculated in line with the UK government guidance (Defra, 2021), and an example of the total benefits in NO_x reduction in the AEF scenario compared with BL scenario is given in Table A9 in the Appendix.

Summary results in Table 4 have shown monetary savings or damages for the alternative scenarios compared to the BL scenario. The associated extra cost of a slower transition to class III BEVs during 2020-2040 is £5,120 million (low £2,562 million, high £7,687 million). Accelerating the market penetration of zero emission vans in the early 2020s could bring a total economic benefit of £12,872 million (low £6,440 million, high £19,323 million). And a 48% of van-km replacement by e-cargo bikes in urban areas could save £5,122 million (low £2,562 million, high £7,687 million). The reduction of NO_x caused by adopting lower NO_x emission factors in the AEF scenario could avoid a damage cost totalling £4,125 million (low £372 million, high £15,807 million) compared to the baseline scenario. The estimation of the economic benefits of different alternative scenarios could support the decision-making process of how much amount of money the government could invest in achieving net-zero in the van sector. (e.g., subsidies for Clean Air Zones (CAZs[18])).

5. Conclusion

This paper projects the future trends of tailpipe CO_2 and NO_x emissions from the van sector during 2020-2040 consistent with a 2030 ICE phase-out plan. Important factors that influence the evolving van fleet population have been proposed and considered. Several alternative scenarios have been designed to assess the impact of different assumptions and the results are summarized in Table 5. In the short-run (year 2020-2030), BEV (including H_2 fuel cell vehicle) share on the road varies between different scenarios, whereas in the long-run (2031-2040) the majority of vans are zero emissions under the 2030 ICE phase-out plan. Results indicates that the phase-out of sales of ICEs (including HEVs/PHEVs) by 2030 will lead to major CO_2 and NO_x emission reductions, and if achieved, the van industry will be on track to achieve the goal of net-zero tailpipe emissions by 2050 under all scenarios. In particular, a rapid transition to BEVs in the early to mid-2020s would significantly lower emissions of carbon, ease the burden of achieving the 4th-6th carbon budget, and the reduction in environmental impacts of this shift has estimated monetary benefits of £1.3 billion compared with the baseline scenario.

Detailed van CO_2 and NO_x emissions in terms of different primary use and powertrains are also estimated. By primary usage of vans, decarbonizing the vans used for 'carrying equipment, tools and materials' is a primary task as they are estimated to be responsible for 61.1% of the total CO_2 and NO_x emissions. By emission standard, increasing the fuel efficiency of diesel ICE Euro 6d vans and scrapping the diesel ICE Euro 5 vans are two immediate priorities to rapidly reduce CO_2 and NO_x emissions. CAZ restrictions, which encourage only the cleanest Euro 6 diesel vans to operate within the boundaries, are making contributions to this transition.

Surface transport is currently the highest GHG emitting sector in the UK. Among the main source of surface transport emissions, vans are the only transport mode whose absolute GHG emissions were still growing between 1990 and 2019 (DfBEIS, 2021a). Unlike passenger cars that could reduce emissions by 'avoiding travel' (reducing the amount of mobility required) (Thornbush et al., 2013; Sikarwar et al., 2021) and 'shifting travel' (transferring from car use to sustainable mode of transport) (Cuenot et al., 2012; Brand et al., 2021; Kazancoglu et al., 2021), demand-side reduction potential (Creutzig et al., 2016) for light commercial traffic is considered to be small, as trends in van traffic are closely linked to business activities (Guo et al., 2016) and would increase with the economy (DfT, 2020b). Therefore, the main approach to achieve net-zero by 2050 in the van sector is the transition to zero emission vehicles. The UK government has confirmed the 2030 end date for sales of ICE vans, however the actual share of BEV sales is still very low now (3.6% in 2021 (DfT, 2022b)). If the BEV uptake speed remains low and only sees a sharp increase in the late 2020s because of the 2030 phase-out plan, that would bring heavy burden on fuel supply, grid capacity and charger infrastructure (Wang et al., 2019). Compared with the baseline scenario in this study, it is shown that a fast BEV adoption in the early 2020s will not only avoid the sudden phase out of ICE vans in the late 2020s but also bring significant monetary benefit with regard to the CO_2 emission mitigation in the van sector.

One limitation of this paper is that ECCo model assumes that the PHEVs and HEVs are phased out at the same time as ICEs in 2030, whereas in reality PHEVs and HEVs would be phased out five years later in 2035. However, through our calculation the annual CO_2 emissions from HEVs/PHEVs are very low, which suggests that the impact of the limitation on predicting van emission trends might be small. If future studies provide a more accurate prediction of sales and stock figures of HEV and PHEV vans, the developed methodology can still be used by policy makers to assess the emission trend in the van sector in the short and long term, and the designed scenarios can still offer some general future orientation to how the key enablers and barriers are going to affect the effectiveness of CO_2 and NO_x emission reduction pace.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

[18] A Clean Air Zone (CAZ) is an area in the UK where targeted action is taken to improve air quality. Depending on the type and the Euro standard, a vehicle may be charged when entering or moving through a CAZ.

Data availability

Data will be made available on request.

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Appendix

Tables A1–Table A9

Table A1
ICE diesel van fleet composition projections by Euro standard during 2020-2040.

Euro standard & registration year	Percentage (%) 2019	2020	2021	2022	2023	2024	2026	2028	2030	2032	2034 (and beyond)
Euro 4 (2007-2011)	32.7%	24.5%	16.8%	11.7%	6.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Euro 5 (2012-2016)	40.0%	40.5%	39.7%	38.1%	37.1%	36.6%	24.5%	9.3%	0.0%	0.0%	0.0%
Euro 6ab (2017-2019)	27.2%	27.5%	27.0%	25.9%	25.2%	24.9%	24.7%	26.5%	20.8%	0.0%	0.0%
Euro 6c (2020)	0.0%	7.5%	7.3%	7.0%	6.9%	6.8%	6.7%	7.2%	8.5%	10.7%	0.0%
Euro 6d-temp (2021)	0.0%	0.0%	9.1%	8.8%	8.5%	8.4%	8.3%	9.0%	10.5%	13.3%	0.0%
Euro 6d (2022-2029)	0.0%	0.0%	0.0%	8.5%	16.1%	23.3%	35.7%	48.0%	60.2%	76.0%	100.0%

Table A2
Van fleet composition projections by class type for different powertrains and Euro standard.

	Diesel ICE vans				Petrol PHEV, petrol HEV and BEV & H_2 fuel cell vehicle
	E4	E5	E6a/b	E6c, E6d-temp, E6d	
Class I	3.9%	4.4%	2.4%	2.0%	2.0%
Class II	35.8%	35.3%	31.1%	31.5%	31.5%
Class III	60.3%	60.3%	66.5%	66.5%	66.5%

Table A3
CO_2 and NO_x emission factors (g/km) of diesel ICE vans by Euro standards and class types.

	E4	E5	E6b	E6c	E6d-temp	E6d
CO_2 emission factors[1] (g/km)						
Class I	126.25	114.25	118.30	117.23	115.39	112.95
Class II	171.78	169.00	171.49	169.91	166.78	163.64
Class III	232.01	243.91	231.70	229.58	225.36	221.12
NO_x emission factors in the baseline scenario[2] (g/km)						
Class I	0.831	1.15	0.96	0.96	0.496	0.248
Class II	0.831	1.15	0.96	0.96	0.496	0.248
Class III	0.831	1.15	0.96	0.96	0.496	0.248
NO_x emission factors in the AEF scenario[3] (g/km)						
Class I	0.77	0.67	0.40	(0.28)	(0.17)	(0.11)
Class II	0.69	0.80	0.22	(0.22)	(0.18)	(0.11)
Class III	0.76	1.04	0.21	(0.27)	(0.16)	(0.10)

[1] PHEM only provides fuel consumption factors (g/km). To predict CO_2 emission factors (g/km), the fuel conversion factor of diesel is taken from the 2021 Government GHG conversion factors (for most users), where 2.97 is used for diesel fuels.
[2] NAEI emission factors are adopted.
[3] NO_x emission rates of Euro 4-Euro 6b are remote sensing results. NO_x emission rates in the brackets are simulated results from PHEM, and a conformity factor of 2.1 for Euro 6d-temp and 1.5 for Euro 6d have been applied to simulated results.

Table A4
CO_2 emissions (g/km) of petrol HEV and PHEV vans by class types.

	Class I	Class II	Class III
Petrol HEV	100.14	122.05	177.81
Petrol PHEV	66.80	81.41	118.60

Table A5
Vans sales and stock by powertrain during 2020-40, under the baseline scenario.

Powertrain	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Van sales											
Diesel ICE	290,359	350,948	313,496	259,272	173,327	0	0	0	0	0	0
Petrol HEV	0	20,912	52,172	51,314	47,856	0	0	0	0	0	0
Petrol PHEV	870	8,664	18,951	11,934	18,648	0	0	0	0	0	0
BEV	6,112	15,152	29,684	119,020	225,354	415,226	423,385	431,226	436,304	443,038	451,187
H_2 Fuel Cell	0	0	17	482	1,394	65,328	65,377	66,987	76,546	87,813	97,903
Van stock											
Diesel ICE	4,218,697	4,330,935	4,348,440	4,214,579	3,884,044	3,273,429	2,558,814	1,897,744	1,316,991	838,179	479,842
Petrol HEV	0	36,040	137,980	239,921	333,624	360,396	332,594	288,317	228,594	161,664	100,911
Petrol PHEV	1,030	16,475	43,248	64,871	95,762	114,297	106,060	92,673	75,168	55,604	36,040
BEV	17,505	41,188	83,406	280,079	671,367	1,355,090	2,162,378	2,936,716	3,643,093	4,245,469	4,721,193
H_2 Fuel Cell	0	0	0	1,030	3,089	71,050	202,852	333,624	473,664	622,971	774,337

Table A6
Urban traffic contribution in each region and country in Great Britain in 2019.

Region / country	Total van traffic share	Urban traffic share in each region / country
North East	3.6%	43.0%
North West	10.6%	44.9%
Yorkshire and the Humber	8.8%	41.3%
East Midlands	8.3%	27.3%
West Midlands	9.1%	40.2%
East of England	11.9%	26.9%
London	6.6%	87.3%
South East	16.0%	30.3%
South West	10.1%	25.8%
Wales	6.0%	29.6%
Scotland	9.1%	33.3%
Total / Average	100%	37.1%

Table A7
Carbon values per tonne of CO_2 and damage costs per tonne of NO_x in the road transport sector*.

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040
Carbon values (£/tCO_2e), in 2020 prices (DfBEIS, 2021d)																					
Low	120	122	124	126	128	130	132	134	136	138	140	142	144	147	149	151	153	156	158	161	163
Central	241	245	248	252	256	260	264	268	272	276	280	285	289	293	298	302	307	312	316	321	326
High	361	367	373	378	384	390	396	402	408	414	420	427	433	440	447	453	460	467	474	482	489
NO_x damage cost (£/ton), in 2017 prices (Ricardo, 2020)																					
Low	817																				
Central	9,066																				
High	34,742																				

* Policy analysis used high and low ranges as part of sensitivity analysis to account for uncertainties. For carbon values, a plus or minus 50% sensitivity range has been deemed appropriate around the central series. For NO_x damage costs, sensitivity range explored the uncertainty around the NO_x exposure and health impact.

Table A8
Central estimate of total benefits of the change in CO_2 emissions in the RB scenario compared with the BL scenario[*,**].

	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
Annual CO_2 savings (tonnes)	0	226,227	954,939	1,971,158	2,828,599	3,257,775	3,146,299	3,005,326	2,785,320	2,232,219	1,572,502
Carbon value	£241	£248	£256	£264	£272	£280	£289	£298	£307	£316	£326
Carbon value rebased to 2022	£247	£254	£263	£271	£279	£287	£296	£306	£315	£324	£334
Total benefit (million)	£0	£58	£251	£534	£789	£935	£932	£918	£877	£723	£513
Total present value benefit (million)	£12,872										

[*] All figures are rounded, but exact values were used in calculations.
[**] Only calculation of the even-numbered years is shown in this table due to page layout limitation.

Table A9
Central estimate of total benefits of the change in NO_x emissions in the AEF scenario compared with the BL scenario[*,**].

	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040
NO_x emission reduction (tonnes)	30,851	35,606	35,201	32,912	30,389	23,163	11,919	5,080	3,525	2,243	1,284
NO_x damage costs road transport	£9,066	£9,066	£9,066	£9,066	£9,066	£9,066	£9,066	£9,066	£9,066	£9,066	£9,066
Damage costs rebased to 2022	£10,270	£10,270	£10,270	£10,270	£10,270	£10,270	£10,270	£10,270	£10,270	£10,270	£10,270
uplift factors	1.0612	1.1041	1.1487	1.1951	1.2434	1.2936	1.3459	1.4002	1.4568	1.5157	1.5769
Damage costs uplifted	£10,899	£11,339	£11,797	£12,274	£12,770	£13,286	£13,823	£14,381	£14,962	£15,566	£16,195
Total benefit (million)	£336	£404	£415	£404	£388	£308	£165	£73	£53	£35	£21
discount factor	1.0000	0.9335	0.8714	0.8135	0.7594	0.7089	0.6618	0.6178	0.5767	0.5384	0.5026
Total discounted benefit (million)	£336	£377	£362	£329	£295	£218	£109	£45	£30	£19	£10
Total present value benefit (million)	£4,125										

[*] All figures are rounded, but exact values were used in calculations.
[**] Only calculation of the even-numbered years is shown in this table due to page layout limitation.

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