Technical Note

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1. Introduction

This technical note has been produced to present the carbon assessment of the six Link & Ride concept options for the Chippenham to Bath bus offer with local interchange sites along its route (referred to as L&R, from this point forward).

The bus service would serve local towns and villages along the A4 corridor with linkage to other key destinations within the centre of Bath. Detailed scheme objectives are outlined in the main report which capture a need to improve the quality of public transport provision in the east of Bath corridor and in doing so reduce the number of car trips travelling into central Bath, thereby reducing carbon emissions and addressing the climate emergency.

This technical note provides an overview of the assessment of the impact of a number of L&R options on carbon emissions, considering both:

- Net additional emissions generated by the new and any re-specified bus services.
- Emissions savings associated with reduced numbers and lengths of car trips due to mode switch to the L&R.

Carbon impacts have been modelled for a baseline L&R service plus six alternative options which vary key features including, frequency, route, charging and bus priority measures.

The baseline service is the current X31 service which currently routes through Corsham. The other tests are for a direct bus service which routes directly along the A4 corridor between Chippenham and Bath, other than scenario K which is for an alternating direct & X31 service offer. Note that for scenario K the assessment has only been undertaken for the direct service (not the existing X31 service) in order to understand the level of additional carbon emissions generated.

A summary of the baseline scenario and the six alternative scenarios captured in the carbon assessment is presented below:

- Test A Baseline - Current X31 route.
- Test B Direct route - 4km shorter than X31.
- Test D Frequency - Increase frequency.
- Test E Fares - Cap fares at existing P&R fare level.
- Test F Bus priority measures - Reduced bus JT to reflect bus priority.
- Test J Combined option - Higher frequency, lower fares and bus priority measures.
- Test K Alternating direct & X31 service offer - Alternating direct & X31 service offer.

2. Methodology

2.1. Transport model inputs

The carbon emissions assessment focussed on the impacts of the forecast change in car and bus vehicle kilometres as a result of the L&R concept options.

Annual car vehicle kilometres for each scenario and origin-destination (OD) pair and total annual vehicle kilometres for the proposed bus service were extracted from the demand assessment (see demand modelling methodology note - Appendix B) to inform the carbon assessment.

The forecast change in car vehicle kilometres as a result of the scheme was disaggregated by the speed bands listed in Table 2-1 on the basis of the traffic conditions on the road that the vehicle kilometres were assumed to be removed from. The speed classification methodology is reported further in the next section.

Table 2-1 - Speed categories

Speed category	Lower limit (mph)	Upper limit (mph)
< 5 mph	0	5
5 - 10 mph	5	10
10 - 15 mph	10	15
15 - 20 mph	15	20
20 - 25 mph	20	25
25 - 30 mph	25	30
30 - 35 mph	30	35
35 - 40 mph	35	40
40 - 45 mph	40	45
45 - 50 mph	45	50
50 - 55 mph	50	55
55 - 60 mph	55	60
60 - 65 mph	60	65
65 - 70 mph	65	70
70 - 75 mph	70	75
75 - 80 mph	75	80

2.1.1. Speed classification

Travel speed has an important influence on vehicle emissions. As link-based traffic and speed data was not available from the model, a simplified approach to speed classification was adopted. The main aim was to reflect the difference in travel speed expected for the car vehicle kilometres removed by L&R that would have occurred outside the city centre and those that would have occurred on the more congested city centre roads.

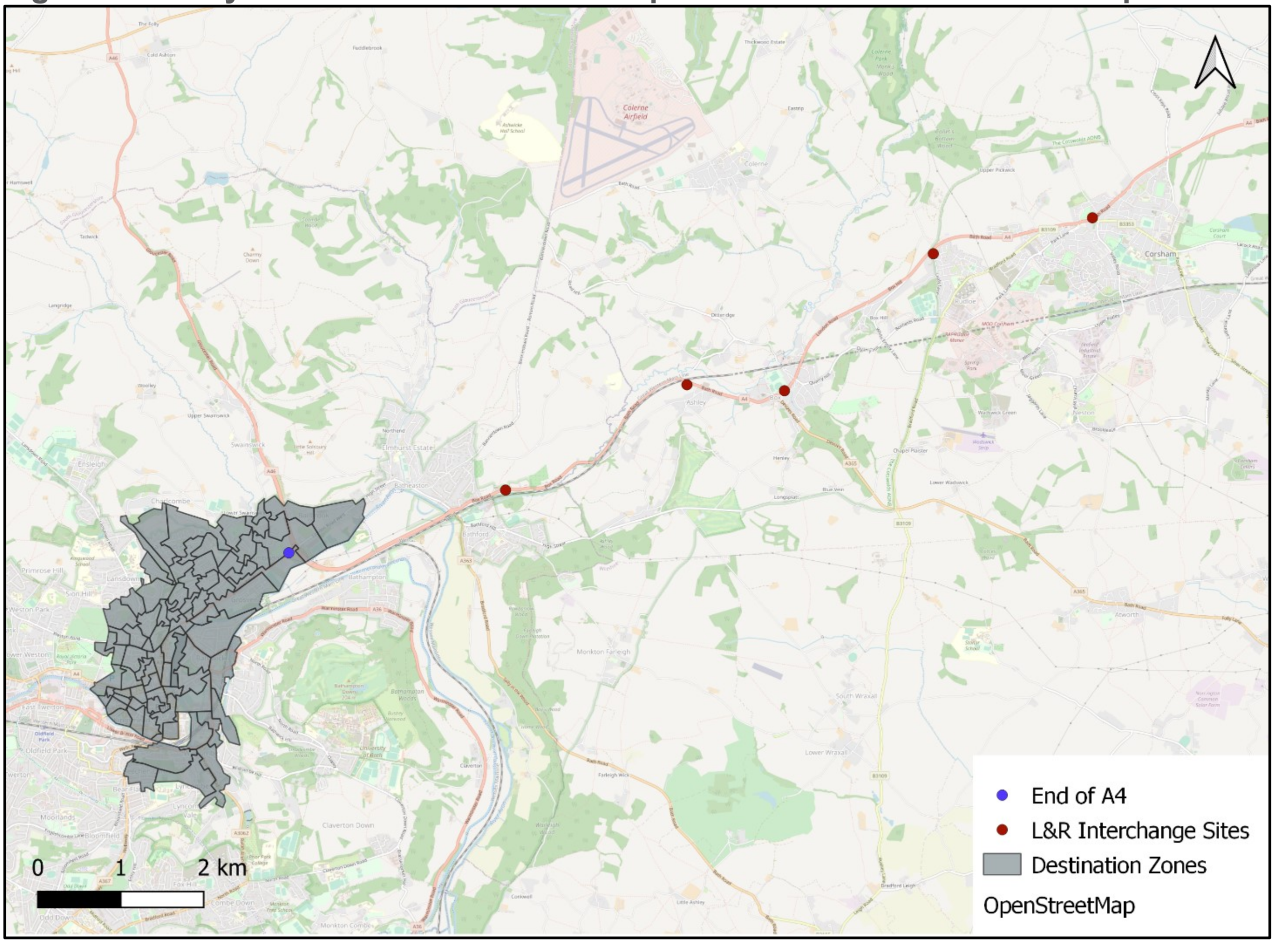
For the purpose of this exercise it was assumed that all car vehicle kilometre savings occurring outside the city centre as a result of the scheme would be taken off the A4 itself. This is based on the likely routings of car journeys and the principle that this is the main arterial route into the city that would be used by those travelling from the in-scope origin zones if travelling by car rather than L&R.

As such the reduction in car vehicle kilometres caused by a mode switch to L&R for each OD pair was allocated two speed classifications reflecting:

- **Average speed of external vehicle kms:** average speed from allocated L&R interchange site, up to the end of the A4 (i.e. the portion of the car journey that would have occurred on the A4 in the absence of the L&R).
- **Average speed of internal vehicle kms**: average speed for the portion of the journey from the end of the A4 to the city centre destination zone (centroid).

The location of all sites used in the speed classification exercise are presented in Figure 2-1. Average speeds for the external and internal journey sections were obtained from journeys time and distances between sites of interest, calculated using a Bing Maps API tool, based on average car journey time data.

Figure 2-1 - Key locations used to inform speed classification of each OD pair



2.2. Emissions calculations

2.2.1. Scope

The carbon assessment captured the primary emissions impacts of the L&R concept i.e.:

- Net additional emissions generated by the new and any re-specified bus services.
- Emissions savings associated with reduced numbers and lengths of car trips due to mode switch to the L&R.

Secondary emission impacts as a result of changes in traffic speed and traffic volume (due to additional bus vehicle kilometres and fewer car vehicle kilometres) were not assessed. They were scoped out as the detailed speed information required for the assessment is not available from the traffic modelling and the impacts would be small in scale relative to the impacts of the additional and removed vehicle kilometres. The scale of the impact would be further reduced by the fact that it would be the net effect of some increases in emissions, where traffic speeds change to a less efficient level and some decreases in emissions where traffic speeds change to a more efficient level.

2.2.2. Emissions calculations - buses

Bus emission factors were extracted from the DfT's Transport Energy Model[1] (well to wheel[2] emission factors in $kgCO_2e$/vehicle km). The factors used for 2017 are presented below:

- Diesel - 1.244 kgCO2e/km
- Efficient diesel - 1.123 kgCO2e/km
- Diesel hybrids - 0.895 kgCO2e/km
- CNG - 1.398 kgCO2e/km
- Hydrogen fuel cell electric - 0.689 kgCO2e/km
- Battery electric - 0.448 kgCO2e/km

Factors for years after 2017 were derived by applying the efficiency improvement assumptions by year and the reduction in carbon intensity of electricity generation (for electric buses) set out in DfT's TAG databook[3].

It is important to note that these factors are likely to be an overestimate as the TEM assumes all buses are double decker.

For the purpose of this report, bus emissions have been calculated assuming either a fully diesel or fully electric fleet, but further sensitivity tests could be conducted in the future to understand the impacts of varying bus fleet composition.

2.2.3. Emissions calculations - cars

Emissions estimates for the change cars vehicle kilometres were calculated in three steps:

- Allocation of the change in vehicle kilometres caused by each L&R option to a vehicle fuel type (petrol, diesel or electric). The DfT's TAG databook[4] provides a projection of fleet composition and change through time. This was used for one estimate of the emissions impact. However, the projection pre-dates the ban on petrol and diesel

[1] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/739462/transport-energy-model.pdf
[22] Well to wheel emissions factors account for emissions associated with producing and transporting the fuel/energy, upstream of the fuelling point as well as Tank to Wheel emissions (i.e. emissions associated with vehicle use).
[3] This approach averaged out fleet upgrades over the course of the appraisal period, assuming bus emissions were consistent with the fleet average in each year rather than applying a s
[4] TAG Databook

(internal combustion engine, ICE) car and van sales from 2030 announced by government in November 2020. Therefore, additional assessments were also undertaken using estimates of the impact of an ICE sales ban in 2030 or 2040 on fleet composition (drawing on forecasts produced by UKERC[5]).

- Calculation of fuel consumption/electricity use for the annual change in vehicle kilometres for each fuel/energy type in each speed band in each year. The calculations used the DfT's TAG databook fuel consumption formulae which relate fuel consumption to vehicle type, fuel type, speed, year, and distance of travel, as well as the change in vehicle efficiency through time.
- Conversion of change in fuel and electricity consumption estimates to estimated change in emissions impacts by year using the DfT and BEIS carbon intensity factors (kg CO_2e/ litre of fuel or kWh of electricity) by year. The change in carbon intensity of electricity generated was derived from the BEIS projections, as used in the TAG databook.

[5] UK Energy Research Centre response to government consultation on ICE ban, 2020

3. Results

3.1. Introduction

The forecast impact of the proposed L&R bus services on carbon emissions are presented below for each option, showing:

- **Additional carbon emissions** generated from the L&R bus service concept tests (Figure 3-1).
- **Emissions savings** associated with reduced numbers and lengths of car trips due to mode switch to the L&R (Figure 3-2).
- **Net additional emissions** generated by the balance between additional carbon emissions from the L&R concept service and the emissions savings from car trips (Figure 3-5, Figure 3-6 and Figure 3-7).

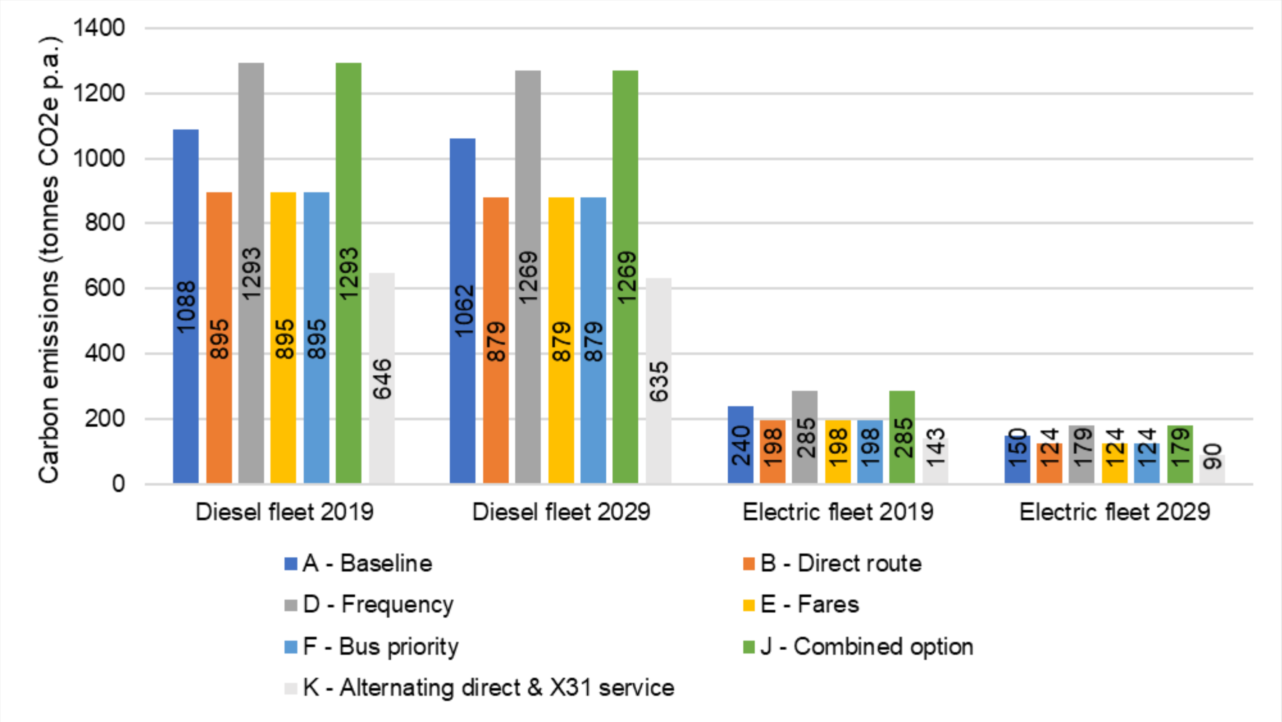
3.2. Additional carbon emissions generated

Figure 3-1 shows the impact of bus frequency and bus fleet on emissions totals. Emissions for scenario D (frequency) and scenario J (combined option) are approximately 45% higher than scenarios B (direct route), E (fares) and F (bus priority). The emissions for Scenario A (baseline) falls around mid-way between the two values, reflecting the increased route length for the baseline. Emissions for scenario K (alternating direct & X31 service offer) are around 50% lower than scenario D and scenario J, reflecting the decreased frequency of the direct service offer (emissions have not been calculated for the X31 service offer as these are existing emissions).

For the diesel fleet tests, emissions in 2029 are approximately 2% lower than emissions in 2019, reflecting the slight improved efficiency in average diesel buses assumed through time in TAG.

The use of an all-electric fleet is estimated to reduce carbon emissions by over 75% in 2019 relative to an all diesel fleet and by over 85%.by 2029 as a result of the reduced emissions intensity of electricity generation in future years.

Figure 3-1 – Additional carbon emissions generated by the L&R bus service (tonnes CO_2e p.a.)



3.3. Emissions savings associated with reduced numbers and lengths of car trips due to mode switch

Figure 3-2 to Figure 3-4 summarise the car emissions savings generated by each scenario, reflecting the number of trips encouraged to switch mode from car to L&R as a result of the scheme and the length of the car trip avoided.

The results clearly show the impact of reduced fares (in scenario E (fares) and J (combined option)) on mode shift. In 2019, emissions savings are nearly three times higher in scenario E and four times higher in scenario J compared to those in scenarios A (baseline), B (direct route), D (frequency), and F (bus priority) and K (alternating direct & X31 service offer). Scenario J also includes the impacts of bus priority and increased frequency, hence adding approximately 25% to emissions savings.

This suggests that capping fares is more favourable approach to increasing patronage in terms of carbon impacts than increasing the frequency of the service, as it does not lead to an increase in bus vehicle kilometres and therefore bus emissions.

Savings in 2029 are approximately 75% of those in 2019 for scenarios A (baseline), B (direct route), D (frequency), F (bus priority) and K (alternating direct & X31 service offer) and approximately 55% of those in 2019 for scenarios E (fares) and J (combined option). This reflects a reduction in mode switch and reduced average emissions of the car fleet, as a result of increased use of electric vehicles and increased efficiency of petrol and diesel cars.

The scenarios assuming a ban on petrol and diesel (ICE) car and van sales in 2030 and 2040 show a more marked reduction in emissions impacts between 2019 and 2029, reflecting the impact of the more rapid electrification of the fleet in reducing car emissions.

Results are presented for three fleet projection assumptions to reflect the potential impact of a ban on petrol and diesel car and van sales from 2030, as announced by government in November 2020. The three fleet projections are as follows:
A) Standard TAG fleet projection (no ICE ban).
B) Adjusted TAG projection, reflecting ICE sales ban in 2040 (based on UKERC forecasts).
C) Adjusted TAG projection, reflecting ICE sales ban in 2030 (based on UKERC forecasts).

Figure 3-2 - Emissions savings associated with reduced numbers and lengths of car trips due to mode switch to the L&R – TAG projections

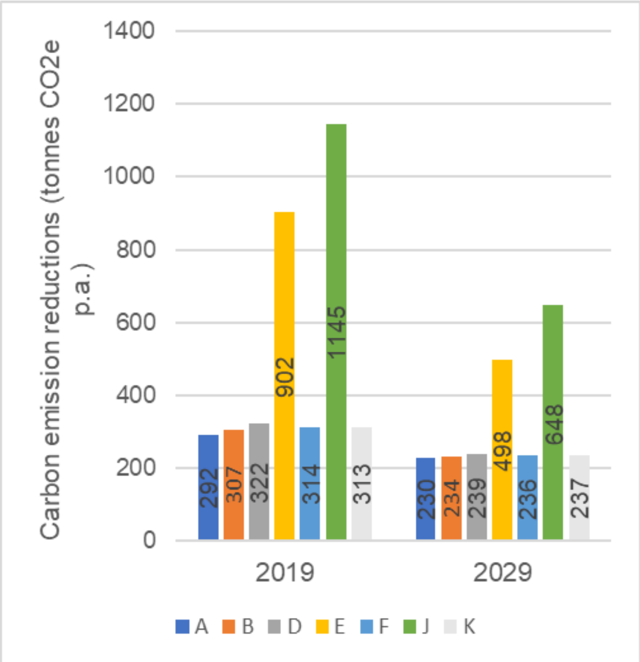


Figure 3-3 - Emissions savings associated with reduced numbers and lengths of car trips due to mode switch to the L&R – ICE ban 2040

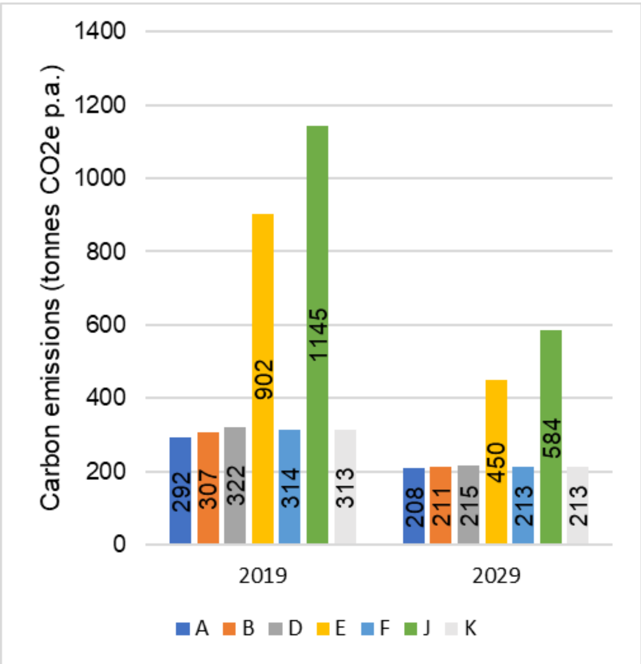
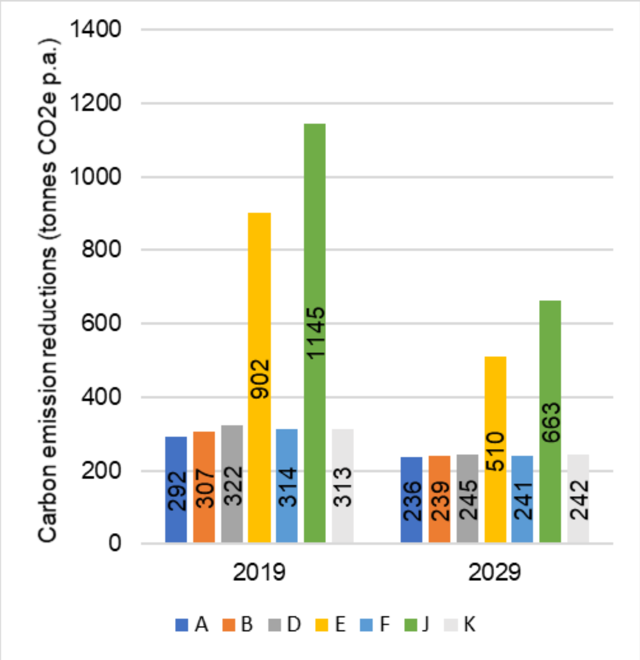


Figure 3-4 - Emissions savings associated with reduced numbers and lengths of car trips due to mode switch to the L&R – ICE ban 2030



3.4. Net additional emissions

By comparing the level of additional emissions generated from the various L&R scenarios with the emissions savings generated through reduced car use as people switch to L&R it's possible to see the overall net impact on levels of emissions as a result of introducing a L&R on the A4 corridor under the various scenarios.

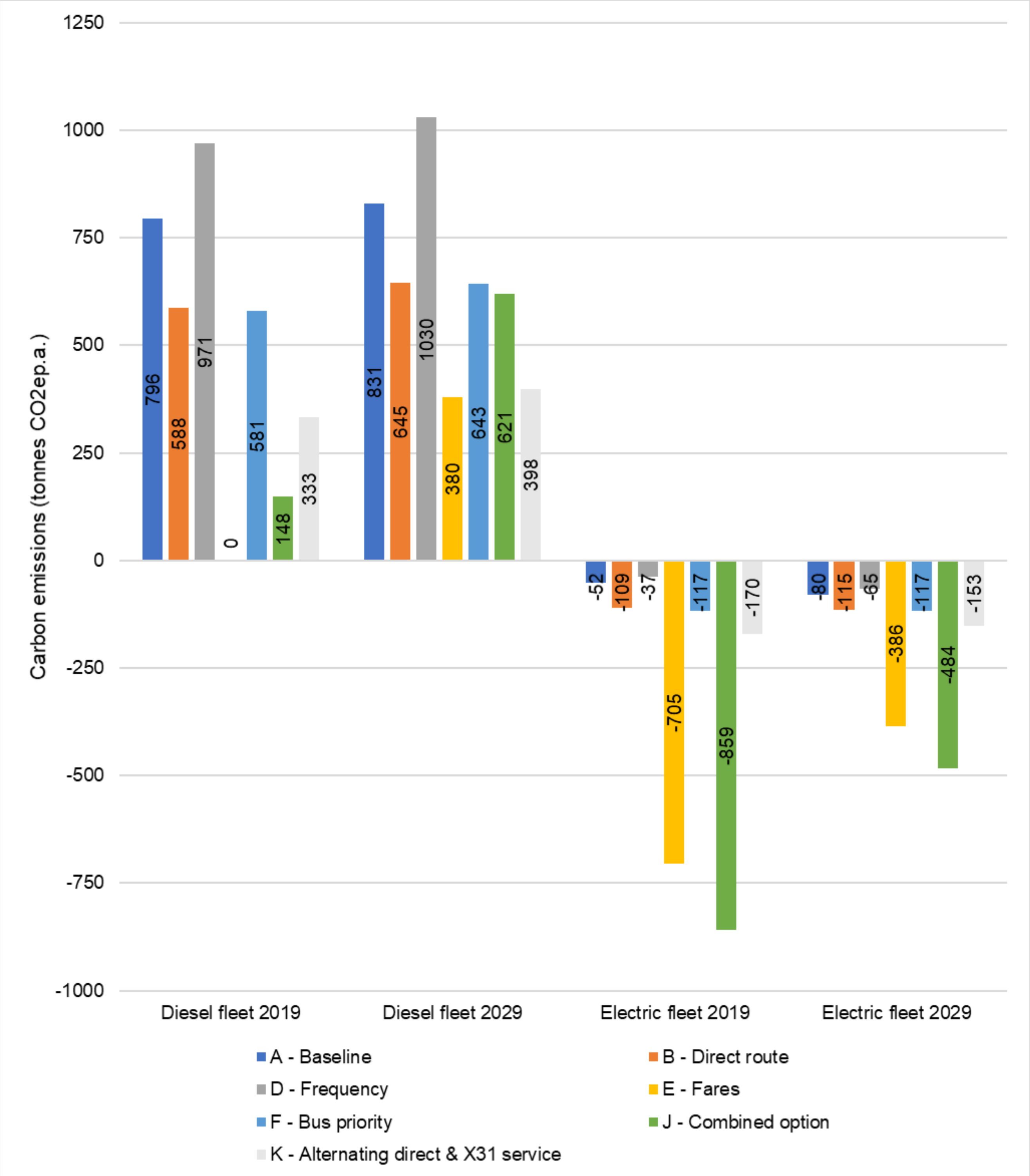
Figure 3-3 shows the resultant balance between the additional emissions generated through the various different L&R service options and the emission savings achieved through a reduction in car vehicle kilometres as drivers shift mode to the new L&R service (based on standard TAG vehicle projections).

It shows that an all-diesel L&R bus fleet would lead to a net disbenefit for scenarios A (baseline), B (direct route), D (frequency), F (bus priority), J (combined option) and K (alternating direct & X31 service offer) in both 2019 and 2029. This is due to there being insufficient car vehicle kilometre savings to offset the additional carbon impacts of introducing a new diesel bus service (noting that buses have a higher emissions factor than a private car). In the case of scenario E (fares), where increased patronage is encouraged through capping fares, the reduction in car vehicle kilometre forecast for 2019 is sufficient to offset the impact of introducing the new bus service. This is not the case for the 2029 modelled year where the forecast reduction in car emissions is lower due to reduced emission rates per car vehicle kilometre as a result of more efficient vehicles and a higher proportion of electric vehicles.

The results also suggest that reducing fare costs (scenario E) is a more favourable approach to increasing patronage in terms of carbon impacts than increasing the frequency of the service, as it does not lead to an increase in bus vehicle kilometres

If an all-electric bus fleet is assumed then it is forecast that the net impact of bus emissions and reduced car emissions would result in a net carbon saving for all options, with option J performing the best as a result of higher patronage levels (encouraged by capped fares and increased service frequency).

Figure 3-5 - Net CO_2e emissions generated by the L&R service concept tests (tonnes CO_2e p.a.), standard TAG vehicle projections



Forecast net emissions have also been calculated for the two tests capturing the impact of the proposed ICE ban coming into place in either 2040 or 2030. The results are presented in Figure 3-6 and Figure 3-7 for a 2040 ban and a 2030 ban respectively.

The tests show that the distribution of results is largely consistent to the initial test. However, the more rapid electrification of the car fleet associated with a ban on petrol and diesel car sales in 2030 will lead to a reduction in the scale of car emissions savings generated by the scheme by 2029.

Figure 3-6 - Net CO_2e emissions generated by L&R concept service tests (tonnes CO_2e p.a.), ICE ban 2040

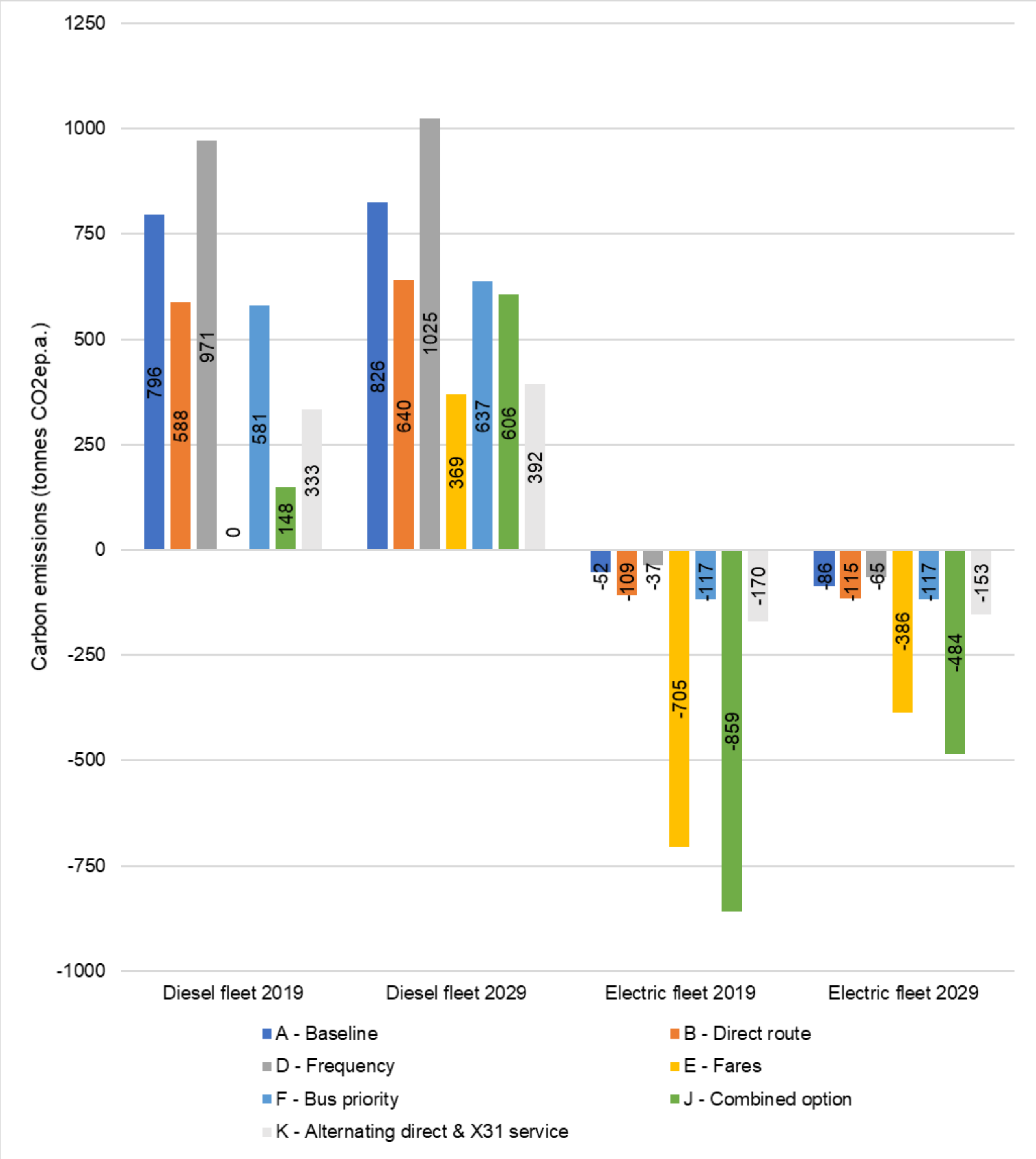


Figure 3-7 - Net CO_2e emissions generated by L&R concept service tests (tonnes CO_2e p.a.), ICE ban 2030