ARUP

Lumo

Avoided Emissions Assessment

Project Report

Final report | 14 December 2023

This report takes into account the particular instructions and requirements of our client. It is not intended for and should not be relied upon by any third party and no responsibility is undertaken to any third party.

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Executive Summary

This report summarises results of the Lumo avoided emissions assessment, which sought to develop and demonstrate a methodology for the calculation of avoided emissions for this open access rail operation. This work provides a new means through which Lumo can measure the positive greenhouse gas emission impacts of its service, enabling market-leading environmental reporting.

Avoided Emissions are defined as emissions reductions that occur as a result of a low-carbon product or service replacing existing and higher-carbon alternatives; through quantifying the difference between emissions resulting from the low-carbon and existing solutions, avoided emissions may be demonstrated. Our assessment has been based on the guidance provided by the Avoided Emissions Framework[1], which sets out best practices for quantifying and communicating such metrics.

Our assessment found that for 2022/23 operations, **Lumo's avoided emissions totalled 60.6 ktCO_2e** with a carbon abatement factor (the functional unit for the Avoided Emissions intensity of Lumo operations) of 0.12 kgCO_2e/passenger km for passengers using its services. This total decarbonising impact equates to the annual emissions from 13,475 petrol-powered passenger vehicles or the energy consumed by 7,632 homes in a year.[2] These results highlight the benefits brought by Lumo in reducing the climate impact of UK transport, with avoided emissions being over 8 times the total operational emissions associated with Lumo operations.

Following this assessment, FirstGroup and Lumo may wish to incorporate avoided emissions into wider Environmental, Social, and Governance (ESG) reporting. The methodology has been proved robust and produced plausible results for the Lumo operation. This should be scalable and applicable to other networks but may need some adaptation for those with more complex operations.

[1] Mission Innovation & Net-Zero Compatible Innovations Initiative. (2020). The Avoided Emissions Framework (AEF).
[2] Calculated by the EPA Greenhouse gas equivalents calculator.

1. Introduction

1.1 Aims

The aim of this study is to establish a methodology for how Avoided Emissions can be quantified for Lumo services. Launched in 2021, Lumo is an open access train operator owned by FirstGroup, travelling exclusively on the East Coast Main Line between London and Edinburgh, calling at Stevenage, Newcastle & Morpeth. This assessment has sought to develop a calculation approach, reporting template, and show how this KPI can supplement FirstGroup's wider ESG reporting and the marketing of Lumo's environmental credentials.

The concept of avoided emissions is that a decarbonisation solution enables existing activities to be performed with significantly less greenhouse gas emissions. Hence, avoided emission assessments represent the evaluation of emissions reductions that result from a low carbon product or service in comparison to the status quo. As an operator of electric, low-emission rail services between destinations often served by air travel, avoided emissions reporting provides Lumo the opportunity to gain a measurable indicator of their decarbonising impact. The assessment can help to build the case for Lumo trains and for scaling low-carbon rail more broadly.

Reflecting on the power of avoided emissions assessments in providing insights for climate-aligned decision-making and purpose definition, Lumo commissioned Arup to undertake an avoided emissions assessment for their services over Financial Year 2022-23 (FY23).

1.2 Avoided Emissions Framework

The Avoided Emissions Framework aims to provide a consistent approach to assess and account for avoided emissions. An aim of the Framework is to complement carbon accounting approaches which encourage emitters to improve existing operations, with a metric that demonstrates the benefits brought by low carbon alternatives to business as usual.

The Framework sets out that avoided emissions can be calculated by comparing emissions from a low carbon product or service to the emissions which would have occurred using business-as-usual (BAU) alternatives, representing those emissions that would have occurred were the enabling solution was not introduced. Lumo's avoided emissions can therefore be defined through the following equation:

$$Net\ Avoided\ Emissions = BAU\ Baseline\ Emissions - Emissions\ from\ Lumo\ services$$

Through this equation, solutions that avoid emissions will deliver a net overall reduction in greenhouse gas emissions. Enabling solutions can then be assessed by determining a carbon abatement factor that reflects the net avoided emissions per unit of the implemented solution. In this case, Lumo as a low carbon solution can be evaluated in terms of $kgCO_2e$ per passenger kilometre.

As of September 2023, over 2000 companies report avoided emissions from products and services to the Carbon Disclosure Project (CDP)[3]. Within the rail industry, the French multinational rolling stock manufacturer Alstom report the combined avoided emissions for their rolling-stock; digital integrated system; and train services as low-carbon solutions[4]. Alternatively, in freight rail sector, CSX disclose avoided emissions provided by their fuel-efficient freight service[5]. Avoided emissions have also been leveraged as a metric to disclose positive environmental impact in other transport sectors. BMW Group report on avoided emissions associated with their battery electric vehicles and plug-in hybrid electric vehicles[6].

[3] Lazard Asset Management. (2023). Decoding Avoided Emissions: Are Current Methodologies Reliable.
[4] Alstom 2022 CDP Submission.
[5] CSX 2023 CDP Submissions.
[6] BMW 2021 CDP Submission.

The completion of this report marks the progress made in reaching the final stage of ‘Steps for quantifying avoided emissions’, as proposed by the Framework and as outlined in Figure 1. Remaining actions concerning validation are addressed in the Discussion and Next Steps section.

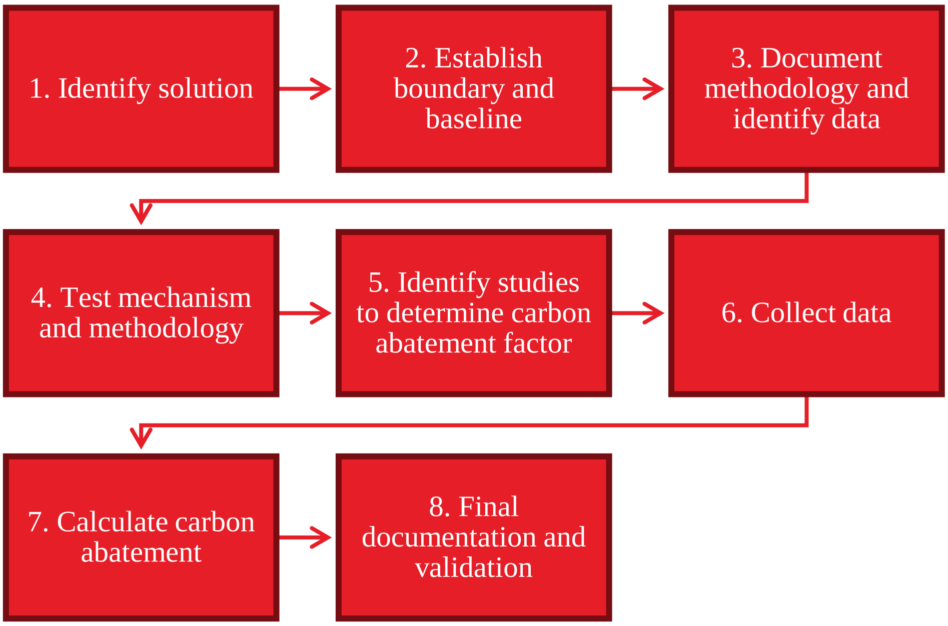

Figure 1: The Avoided Emissions Framework ‘Steps for Quantifying Avoided Emissions’

In alignment with the reporting guidance provided by the Framework, our methodology presented below clearly states any assumptions made and references data sources appropriately. Moreover, consistent with the recommendations of the Framework, the emission factors applied to assess both the baseline (counterfactual) scenario and Lumo journeys reflect the full lifecycle emissions. For example, well-to-tank emissions are included in the assessment of both the alternative transport modes in the assessment of baseline BAU emissions and for Lumo journeys.

2. Methodology

The chart displayed below describes the high-level methodology for the Lumo avoided emissions assessment, highlighting the associated data inputs, outputs, and calculations (Figure 2). This methodology is detailed at full length within the appendices of this report, with the following text providing a summary.

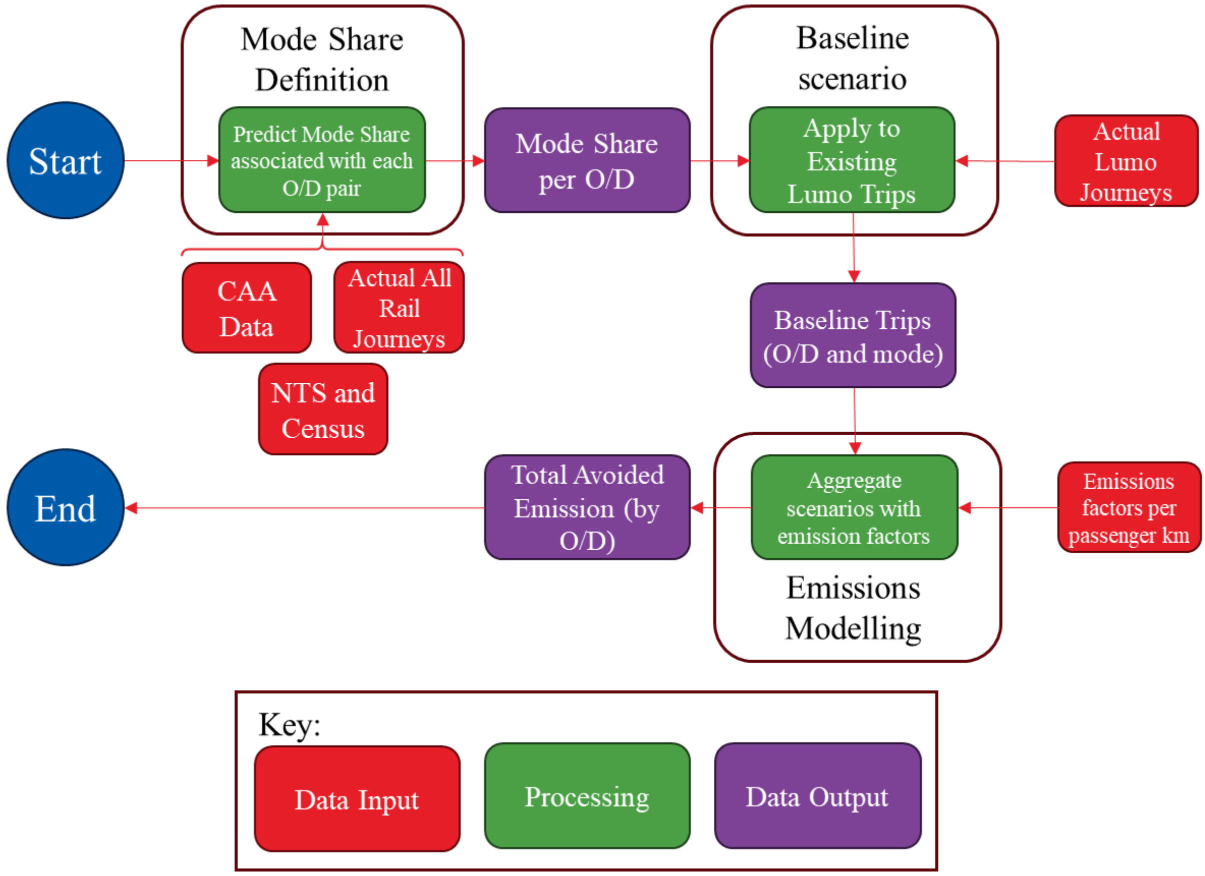

Figure 2: Schematic Diagram for the Avoided Emissions Assessment Methodology

To estimate the emissions avoided by Lumo passengers travelling along the route serviced, a starting point was to model the alternative transport options were Lumo not available. This baseline scenario was produced through modelling the mode share between alternative transport options for each origin and destination pair (O/D pair) served. This enabled the prediction of the average emissions intensity associated with taking a journey without using Lumo, which when compared to the emissions calculated for making that journey using Lumo, allowed the avoided emissions per journey to be estimated. The total avoided emissions delivered through a year of Lumo operations was then derived using this per journey emissions data, and the total recorded journeys made via Lumo over this time period.

The most complex element of this process was estimating the per-journey emissions for the Baseline scenario, where the range of transport means available to passengers needed to be considered for each O/D pair on the Lumo network. To do this, it was assumed that were Lumo not available, passengers would make the journey using either another rail service, private car, bus or coach travel. For routes where air travel is available, this option was also integrated into the baseline model. Based on publically available datasets and Lumo operational data, the alternative mode share for journeys in the baseline scenario was estimated for each O/D pair. The mode share was used with published emissions intensities for alternative transport modes to estimate the average emissions intensity associated with making a journey via a Lumo alternative

To calculate the emissions associated with making a journey via a Lumo service, the Lumo carbon calculator was used. This calculator uses best-practice emissions intensities, data on energy consumption across Lumo operations, and the passenger kilometres travelled to give an accurate emissions intensity reflecting observed data from 2022/23.

The total avoided emissions results were produced through combining the per journey emissions associated with the baseline scenario, and transport via Lumo, with data recording the total journeys across the year. The emissions avoided for each journey were summed to give a total, allowing results by route to be examined.

The datasets used to produce this assessment are detailed in Table 1.

Table 1: Datasets used in modelling.

Model component	Dataset	Source
Baseline scenario	Census Journey to Work data from 2011 detailing national travel patterns for commuters.	Department for Transport
	National Travel Survey data covering journeys made between UK cities, including leisure trips.	Department for Transport
	Population and employment forecasts used to scale 2011 data to current demographics in the National Trip End Model dataset.	Department for Transport
	Passenger numbers between airports for domestic flights, information on their origins and destinations.	Civil Aviation Authority
	Rail demand data for the Lumo route detailing passenger numbers annually, daily, and through other rail operators.	Lumo
Emissions calculations	DESNZ Conversion Factors 2023 for Scope 1, 2 and 3 emissions factors for car, bus and coach travel and for Scope 3 emissions for rail and air travel.	Department for Energy Security and Net Zero
	Power of One" Campaign' (2022) report provided an LNER specific emissions factors for baseline rail travel emissions.	UCL MaaSLab
	ICAO Carbon Calculator provided air travel emissions factors for journeys between all relevant airports	International Civil Aviation Organisation
	Lumo trip emissions and trip distanced sourced from the Lumo Carbon Calculator	Lumo

3. Findings

3.1 Summary findings

Using the above methodology, we estimate that over FY23, Lumo helped customers to avoid emitting a total of 60.6 ktCO_2e by using their rail services, equivalent to a carbon abatement factor (the functional unit of avoided emissions for Lumo services) of 0.12 kgCO_2e/passenger.km. This figure represents over eight times the total organisational emissions generated by Lumo over the same period, when applying a market-based calculation approach. An avoided emissions number of 60.6ktCO_2e is equivalent to the annual greenhouse gas emissions generated by 13,475 petrol-powered passenger vehicles or energy consumption by 7,632 homes[2]. Alternatively, this represents the same emissions generated by the combustion of over 25,000,000 litres of petrol or over 30,000,000 kg of coal.

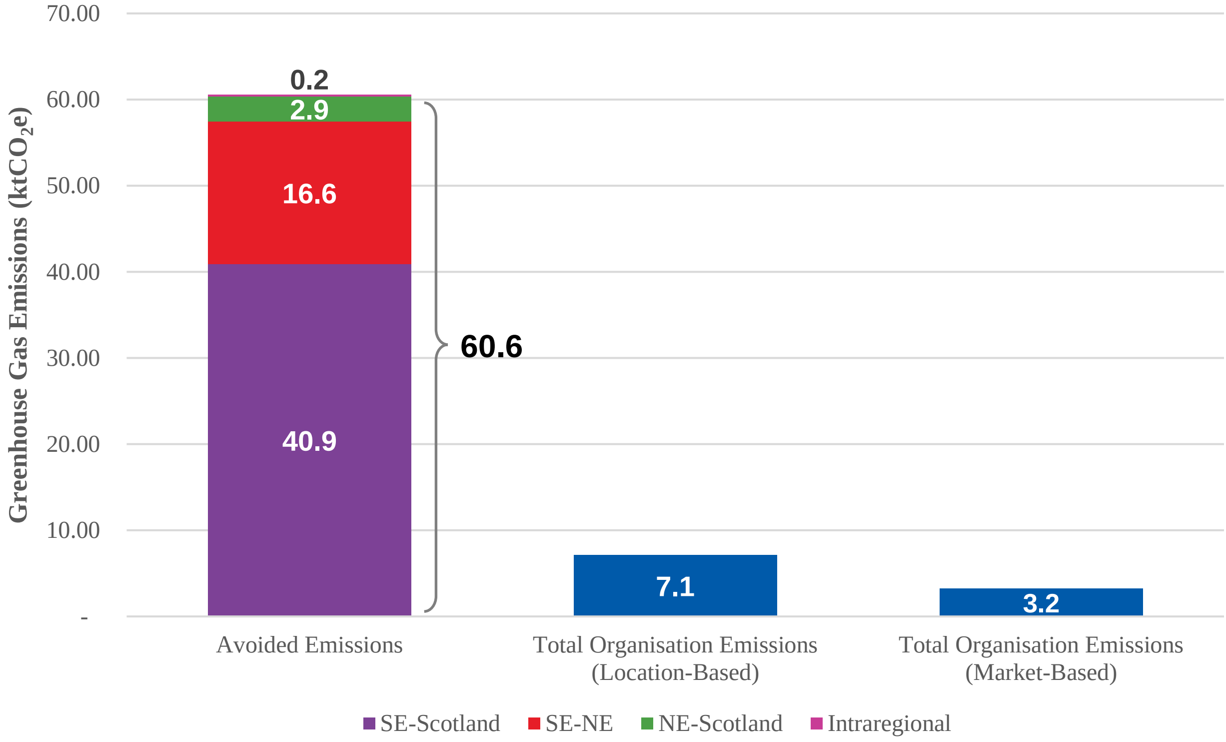

Figure 3: Lumo avoided emissions split by trip for FY23 in relation to against organisation emissions

Two thirds of these emissions (40.9 ktCO_2e) were avoided through the operation of Lumo services between SE England and Scotland, whilst 27% resulted from Lumo services between the SE and the NE (Figure 3). Intraregional Lumo services (i.e., Newcastle-Morpeth) and journeys between the NE and Scotland allowed for a much smaller proportion of the avoided emissions, representing just 5% of the total.

Lumo trips from SE England to Scotland avoided the most greenhouse gas emissions (Table 2) both on a per journey and per kilometre basis. The avoided emissions per journey for these routes were nearly double those for journeys between SE England and NE England and almost five times those for journeys between NE England and Scotland. When normalising these avoided emissions values for the distance (km) travelled, the same relationship held.

Table 2: Avoided Emissions per journey and per journey km

Regional Trips	Avoided Emissions per Journey (kgCO_2e)	Avoided Emissions per Journey km (kgCO_2e/km)
SE to Scotland	**79.9**	**0.13**
SE to NE	**44.7**	**0.10**
NE to Scotland	**16.6**	**0.08**

The avoided emissions per mode and for each pair of areas of interest is depicted in Figure 4. Air travel is the main source of avoided emissions both overall and more specifically for the SE England-Scotland corridor. Car travel remains a significant source of avoided emissions, as well, with an almost equal share between the

SE England-Scotland and the SE England-NE England corridors. More moderate emissions have been avoided by the use of other rail services with the majority being attributed in the longest routes between SE England and Scotland. Finally, bus travel is associated with the least emissions across the examined routes due to the low emission factors of that mode.

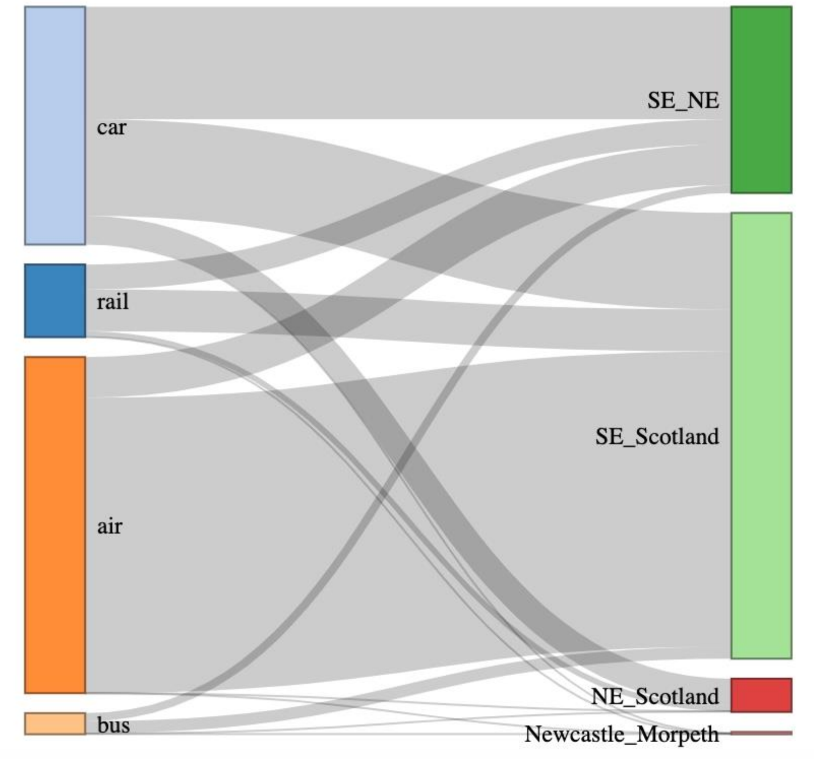

Figure 4: Avoided emissions per mode and area of interest

3.2 Baseline scenario comparison

As detailed previously in the methodology, the key assumption underlying our baseline scenario modelling approach was that in the absence of Lumo services, Lumo passengers would be distributed across transport modes in a ratio consistent with the wider mode share between destinations. We acknowledge that Lumo passengers may have specific preferences or constraints (e.g., no access to a car) that might make their alternative mode choice distribution different from this wider mode share. However, choice modelling to refine this assumption would need significant survey data from travellers to be robust. For this reason, we have looked to bound emissions by looking at scenarios where Lumo passengers all switch to a single alternative mode (Figure 5).

To assess the sensitivity of our avoided emissions assessment, extreme scenarios where Lumo demand was distributed entirely to other rail and then air travel were modelled. This exercise provided perspective on the relative magnitude of our baseline scenario when compared to the upper and lower bounds for avoided emissions. For the ‘all rail’ baseline, mode share was 100% for other rail services across all trip variants. For the ‘all air’ scenario, all trip variants that could be serviced had a mode share of 100% by air, whereas all remaining trips held a mode share determined by our baseline scenario modelling approach. This provided best- and worst-case scenarios for how journeys could be made without Lumo from a carbon perspective and demonstrated that our modelled baseline scenarios represented a middle ground where passengers made their journeys using a range of alternative means.

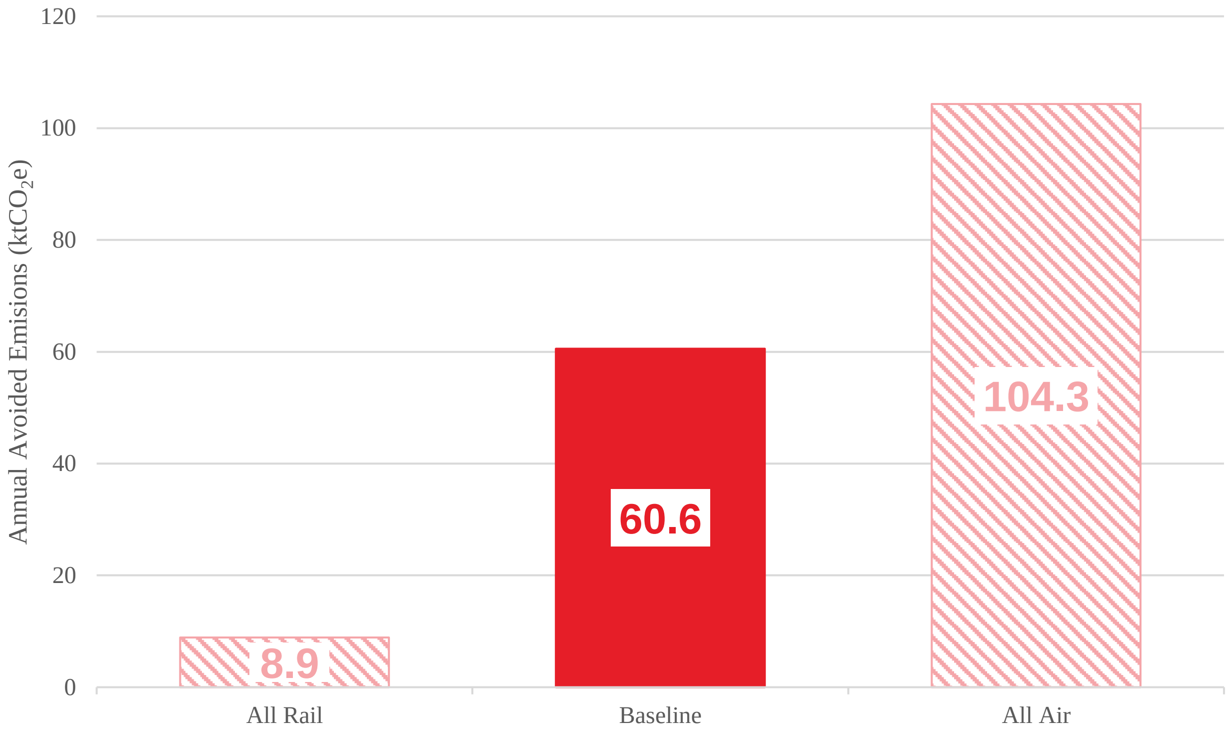

Figure 5: Total annual avoided emissions of the baseline scenario compared to extreme counterfactual scenarios

3.3 Economic implications of carbon savings

The Avoided Emissions Framework shows scale of benefit and is built upon defining a "what-if" counterfactual scenario. By definition, reporting is open to interpretation and it is important the results are communicated clearly. We should therefore remain cautious when considering financial values associated with outputs. Complexity in avoiding double counting and setting boundaries between organisations may further complicate this.

There is planned DfT guidance for 'Quantified Carbon Reduction' and how this can be accounted for as part of Local Transport Plans, however, at the time of this study it had yet to be published. We expect this methodology to be broadly consistent with future guidance, but certain assumptions or values may need to be aligned post-publication.

While the rough economic benefits associated with avoided emissions could be calculated using a carbon price, messaging around number needs to be careful to avoid being perceived as overstating benefits. Avoided emissions are unlikely to be used to support an economic case within a formal business case at this time and are likely not robust enough to count as carbon removals or measured reductions.

A.1 Methodology

The diagram below describes the high-level methodology for the Lumo avoided emissions assessment, with associated data inputs, outputs, and calculations (Figure 6). This process is described in detail in the remainder of this section. In the interests of transparency and consistency, we have focused on the use of public datasets as much as possible, supplemented by Lumo internal data (see Table 3).

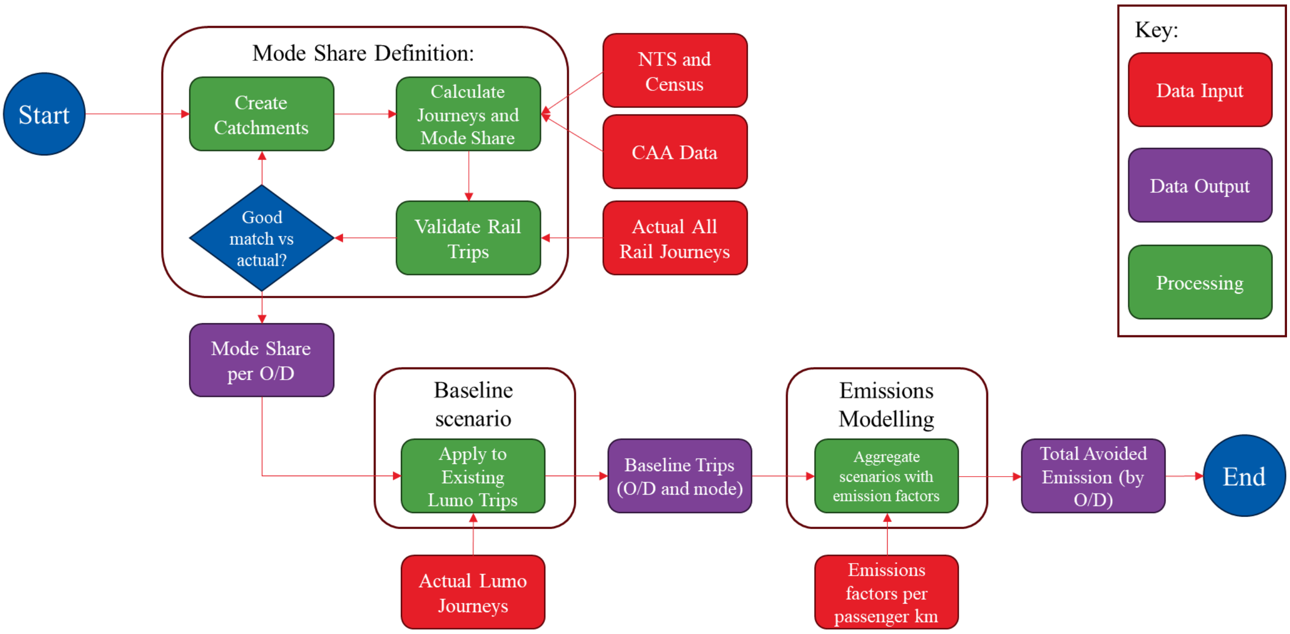

Figure 6: Modelling methodology for calculation of Lumo's Avoided Emissions

We model the number of movements between Lumo's served destinations by car, rail, bus / coach, and air using public survey datasets. We use these movement to define the **baseline scenario** (mode share) for each mode as the proportion of journeys using each mode. We work out how journeys taken on Lumo would have been shifted to the remaining modes, if they had not been made by Lumo, re-assigning Lumo journeys based on the baseline scenario mode share for each Origin/Destination (O/D) pair. That provides us with the total passenger kilometres by each mode in **with and without Lumo** scenarios. We then calculate the emissions of these two scenarios with their difference illustrating the potential amount of avoided emissions due to the operation of Lumo.

A.1.1 Data inputs

Several datasets were utilised for the purpose of defining the baseline scenario and calculating the avoided emissions described in Table 3 along with their respective sources.

Table 3: Utilised datasets

Name	Description	Source
JtW	Journey to Work from the Census 2011, capturing the mode used to reach the usual place of work by the respondent at a day of the week prior to Census 2011. Two versions of that dataset were acquired capturing commuting trips between Middle Super Output Areas (MSOAs[7]) and Local Authority Districts (LADs[8]).	Nomis

[7] Middle Super Output Areas are medium level Census geographical boundaries with a population between 5,000 and 15,000 people. For more details see here. For an interactive map of MSOAs across England and Wales, see here.

[8] Local Authority Districts are administrative boundaries generally adhering to local councils. The city of Edinburgh is a single LAD. At the same time, London is segmented to 33 Boroughs each being its own LAD. For an interactive map of UK's LADs, see here.

Name	Description	Source
NTS	National Travel Survey (2002-2021) is the annual household survey conducted in the UK by the Department for Transport.	Department for Transport
NTEM	Official forecasts of population and employment from 2011 to 2051 at 5-year increments obtained from the National Trip End Model.	Department for Transport
CAA_pax	Passenger numbers between airports for domestic flights from the Civil Aviation Authority (CAA) for the year 2022.	Civil Aviation Authority
CAA_acc_egr_county	Origin/destination counties of terminating passengers for specific airports across the UK and more specifically the South East region for the year 2022.	Civil Aviation Authority
CAA_acc_egr_region	Origin/destination regions of terminating passengers for specific airports across the UK for the year 2022.	Civil Aviation Authority
annual_rail_observed	Annual rail demand between the main and extended stations serviced by Lumo broken down by all rail providers and by Lumo specifically. This dataset was used to validate the modelled demand.	Lumo
daily_rail_observed	Daily rail demand between the main and extended stations serviced by Lumo. This dataset was used to provide an annualisation factor for deriving a modelled annual demand from the initially modelled daily demand.	Lumo
rail_air_shares	Rail/air shares provided by Lumo. This dataset was used to validate the modelled rail/air shares.	Lumo

A.1.2 Baseline scenario definition

A key component of the wider methodology is the definition of the baseline scenario, which seeks to accurately represent the transport options that would be taken by Lumo passengers in the counterfactual scenario where Lumo is not operational.

A.1.2.1 Study area

The analysis was performed for Lumo trips between London King's Cross-Stevenage-Newcastle-Morpeth-Edinburgh stations. Glasgow station was also added to the analysis due to the significant number of trips in the London-Glasgow and Newcastle-Glasgow routes, as reported in the "annual_rail_observed" dataset. The stations included in the analysis are depicted in Figure 7, with the five main Lumo stations and the addition of Glasgow. In total, 11 routes were taken into consideration between these stations accounting for 99.3% of observed Lumo demand. London-Edinburgh, specifically, is the most significant route in terms of observed demand for Lumo (43.9%) followed by London-Newcastle (30%) and Newcastle-Edinburgh (13.5%).

The routes under consideration are:

- London-Newcastle
- London-Morpeth
- London-Edinburgh
- Stevenage-Newcastle
- Stevenage-Morpeth
- Stevenage-Edinburgh
- Newcastle-Morpeth
- Newcastle-Edinburgh
- Morpeth-Edinburgh
- London-Glasgow
- Newcastle-Glasgow

Figure 7: Stations included in the analysis

A.1.2.2 Journey to work matrix reprojection

The Journey to Work (JtW) matrix provides the number of commuting trips between geographical boundaries in the UK per mode. At an initial stage of the analysis, it was decided to base our methodology on the JtW data from Census 2011 instead of using the recently published data from Census 2021 as that was conducted during the COVID-19 pandemic and it could potentially lead to biased findings[9].

We have instead decided to use the JtW of Census 2011 and reproject it to the analysis year of 2023 by using the official forecasts for population and employment growth from the National Trip End Model (NTEM). After obtaining the population/employment forecasts per geographical boundary, the respective percentage growths were calculated relative to the base year of 2011 and applied to the JtW matrix. Due to differences between the statistical authorities of England/Wales and Scotland, there are some discrepancies in the definition of geographical boundaries. As a consequence, JtW for England/Wales is reported at the MSOA level, while the equivalent JtW for the whole of the UK including Scotland is reported at the Local Authority District (LAD) level, which is coarser than MSOA data. We opted to use a combination of both, where for cases with one station located in Scotland, the LAD-based JtW was used, while for station pairs located entirely within England, the MSOA-based version was used.

In the JtW matrix, the rows represent the origin zones, where the home location of the commuters is located, while the columns represent the destination zones, i.e. the zone of the work location. Therefore, the row totals (sum of columns for a specific row-origin zone) represent the total number of commuters living in that zone, also known as production totals, while the column totals (sum of rows for a specific column-destination zone) represent the total number of commuters working in that zone, also known as attraction totals.

The process for reprojecting the base JtW of 2011 to 2023 is based on an algorithmic procedure called Iterative Proportional Fitting (IPF), which is visualised in Figure 8. In summary, IPF is a process that aims to match the row totals with the column totals as closely as possible or until meeting certain stopping criteria. For this study, the set of stopping criteria defined were first to reach a maximum error across rows and columns less than a percentage difference of 2% or -where that was not possible- to stop after reaching 1,000 iterations.

[9] https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/bulletins/traveltoworkenglandandwales/census2021.

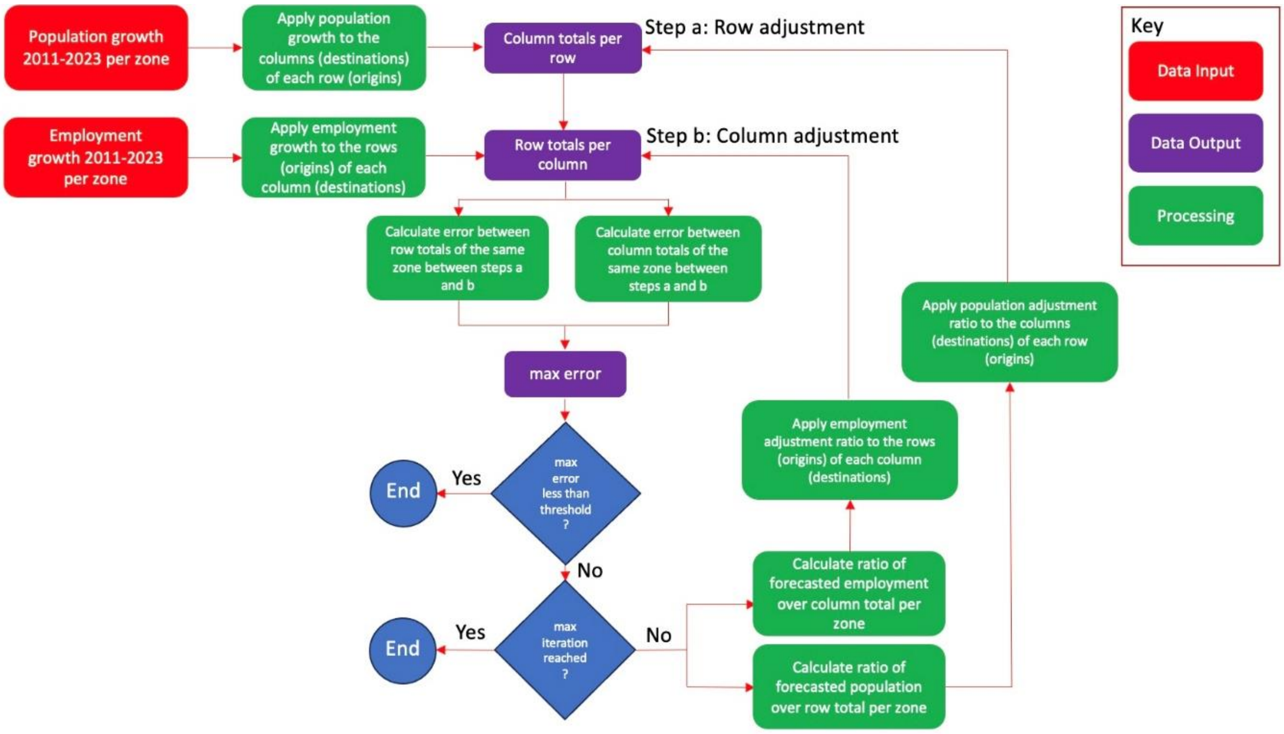

Figure 8: Flow chart of Iterative Proportional Fitting (IPF) algorithm

A.1.2.3 Definition of catchment areas

Following the JtW reprojection to 2023, the catchment areas between each pair of stations had to be found that would lead to a bidirectional rail demand consistent with the data provided by Lumo. For that purpose, an iterative process had to be performed for each pair of stations serviced by Lumo. That process first involved an initial selection of a specific set of zones around each station in a given pair of stations and the summation of all commuting rail trips from the zones around one station to the zones of the other station for both directions.

After that step, the calculation of the purpose split between the origin-destination counties derived from NTS was performed using only data before 2020 to minimise any negative impacts from COVID-19. The shares of trips per purpose were used to expand the commuting trips derived from the reprojected JtW and the respective catchment areas in order to include demand for other purpose trips, as well, and to derive a total bidirectional rail demand.

A.1.2.4 Annualising daily rail demand

The modelled rail demand including all-purpose trips was compared with the "annual_ rail_ observed" data, i.e. the data provided by Lumo. In order to achieve that, we had to define annualisation factors to expand the daily trips into annual figures. This is an important step, as we largely base our methodology on the JtW matrix, which captures the commuting mode used in a day of the week prior to Census (Census is typically performed on a Sunday). Since those trips refer to commuting trips, they are most likely performed on weekdays and we need to account for that in order to safely compare our modelled demand with the observed annual demand.

We were able to derive annualisation factors on a route-by-route basis using data on daily flows for the 2022-2023 financial year provided by Lumo ("daily_rail_demand"). Using that dataset, the relative importance of weekdays (Monday-Friday) vs weekends (Saturday-Sunday) was derived and used to scale upwards or downwards the weekend days relative to weekdays, based on the observed daily variations of rail demand for each of the routes examined. The proposed approach thus takes into account the demand variability both within the week and across the different routes. The previous steps were repeated until a set of zones leading to small discrepancies with the observed annual rail demand was found. After finding the final set of calibrated catchment areas, the respective car and bus commuting demand was derived from those zones. The same commuting share was applied to car and bus demand, as well, to expand the commuting car and bus trips to all-purpose trips.

At this stage, we have modelled rail, car and bus demand, where the rail demand has been calibrated to match the actual rail demand as reported in the "annual_rail_observed" dataset for the 2022-2023 financial year. An example of a calibrated catchment area around each pair of stations for the London-Edinburgh route is depicted in Figure 9 along with the rail stations across the Lumo line (including Glasgow).

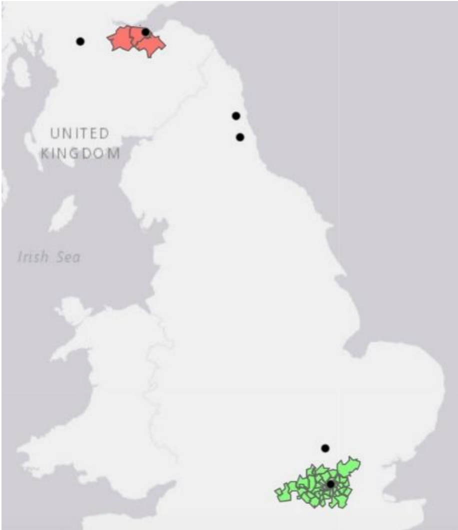

Figure 9: Example of calibrated catchment areas for the London-Edinburgh route

The final modelled bidirectional daily rail demand for each route is presented in Table 4, along with the respective modelled annual demand, the annualisation factor utilised and the real-world annual demand as provided by Lumo (across all rail providers operating in those routes). Modelled demand is below 10% difference from the observed demand for the majority of the routes, while being below 5% difference for the routes with the majority of traffic, i.e., London-Edinburgh, London-Newcastle, Newcastle-Edinburgh, Newcastle-Morpeth and London-Glasgow. The biggest discrepancy is in Stevenage-Morpeth, where we overestimate the demand by 133.08%, although the actual number of trips is not material (relative to the order of magnitude in the remaining routes) to have any meaningful impact on the final results. A graphical depiction of the modelled and observed annual rail trips across the routes examined is also presented in Figure 10.

Table 4: Modelled and observed rail demand

Route	Modelled daily demand (no. trips)	Annualisation factor	Modelled annual demand (no. trips)	Validation data (no. trips)	Percentage difference
London - Edinburgh	5,424.5	360	1,952,820	2,019,028	-3.28%
London - Newcastle	4,098.4	353	1,446,735	1,400,313	3.32%
Newcastle - Edinburgh	2,382.7	295	702,897	724,9167	-3.31%
Newcastle - Morpeth	872.7	320	279,264	282,204	-1.04%
London - Morpeth	138.2	334	46,158.8	48,078	-3.99%
Morpeth - Edinburgh	383.4	246	94,316	105,393	-10.51%
Stevenage - Edinburgh	91.5	349	31,934	29,380	8.69%
Stevenage - Newcastle	90.1	359	32,346	29,421	9.94%
London - Glasgow	1,828.1	320	584,992	584,368	0.11%
Newcastle-Glasgow	345.1	329	113,538	127,423	-10.90%
Stevenage - Morpeth	8.4	351	2,948.4	1,265	133.08%

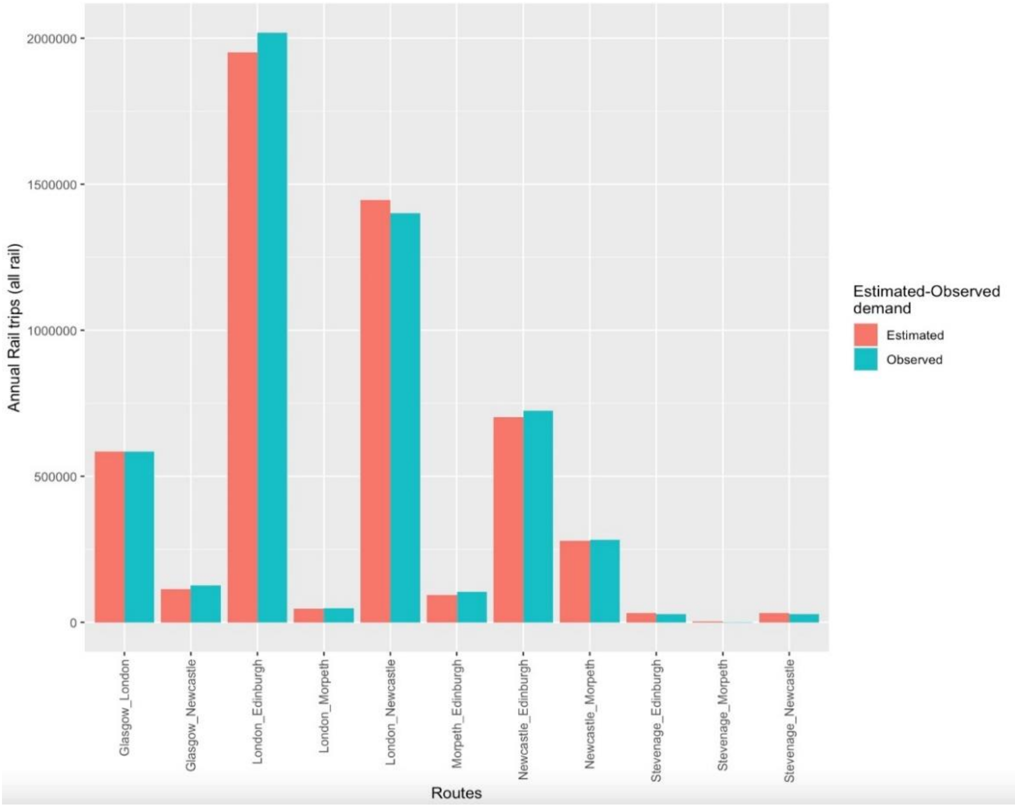

Figure 10: Modelled and observed annual demand across the examined routes

A.1.2.5 Air demand

The last step involves the inclusion of domestic air demand between:

- London/Stevenage - Newcastle/Morpeth
- London/Stevenage - Edinburgh
- London/Stevenage - Glasgow

This was accomplished by using data from the Civil Aviation Authority (CAA), which provides annual passenger numbers between the five London airports, namely Heathrow, Gatwick, Stansted, Luton and City airport and the airports of Newcastle, Edinburgh and Glasgow ("CAA_pax" dataset). The demand between airports is for the most part equal across the two directions.

Not all journeys taken by air between these airports are directly comparable with the journeys offered along the Lumo route. Some of these journeys would represent components of journeys between other O/D pairs, for example where passengers live far from the cities which give their names to the airports. To represent this affect we have used we have used data on the origin and destination of terminating passengers ("CAA_acc_egr") dataset. This data gave us the ratio between journeys into London airports that terminated in the London catchment area defined in our model and journeys that terminated outside of this catchment area. This data was not available for other cities and so the ratio generated for London was assumed to hold for Newcastle, Glasgow and Edinburgh.

In addition, although there is data for terminating passengers from the London airports across the counties of South East ("CAA_acc_egr_county"), there is only available data at the regional level for the neighbouring areas ("CAA_acc_egr_region"). Therefore, there is no data specifically for the county of Hertfordshire within which a core station of our study area is located, namely Stevenage. As a consequence, an approach had to be developed for spatially disaggregating the regional numbers for the East region to each of its constituent counties for the purpose of defining terminating passengers for Hertfordshire. To accomplish that, a range of simple linear regression models was estimated, one for each of the five London airports using the terminating passenger numbers for each of the counties in South East as dependent variables and the population of each county and the distance from each airport as explanatory variables. The purpose of those regressions was to derive a functional relationship among population, distance and the observed numbers of terminating passengers in order to impute the respective numbers of terminating passengers for the missing counties of the East region. The developed approach allowed us to obtain predicted numbers for Hertfordshire and to calculate what percentage of terminating passengers around the five London airports are originating or terminating within the GLA and Hertfordshire. Those shares were multiplied with the total annual demand between each pair of airports, as reported in "CAA_pax", to derive the final air demand for each relevant county and for each airport.

A.1.2.6 Modelled mode share

The final modelled mode share -after including air demand- is presented in Table 5.

Table 5: Modelled mode share across the examined routes

Route	Rail	Car	Air	Coach/bus
London - Edinburgh	31%	14%	44%	11%
London - Newcastle	37%	34%	12%	17%
Newcastle - Edinburgh	46%	45%	0%	9%
Newcastle - Morpeth	12%	68%	0%	19%
London - Morpeth	57%	34%	0%	10%
Morpeth - Edinburgh	31%	68%	0%	0%
Stevenage - Edinburgh	9%	20%	68%	2%
Stevenage - Newcastle	19%	51%	25%	5%
London - Glasgow	20%	8%	68%	5%
Newcastle-Glasgow	14%	82%	0%	4%
Stevenage - Morpeth	35%	65%	0%	0%

As an additional measure of validation, the modelled rail/air ratios across three routes, namely London-Edinburgh, London-Newcastle and London-Glasgow, were compared with ones reported for the 2022-2023 financial year in the "rail_air_shares" dataset produced by Lumo modelling. The results are presented in the following Table 6, where it can be seen that for two out of the three routes examined, the modelled rail/air share is close to the observed values reported. London-Edinburgh route provides the most significant discrepancy, where we are overestimating air demand by around 9%. Possible reasons for this include:

a. The low level of detail in the analysed "CAA_acc_egr" dataset and the fact that there is missing data on terminating passengers for Edinburgh (similar to Newcastle and Glasgow) and for Hertfordshire (relating to Stevenage). As a result, we are in no position to properly capture the catchments areas for air travel from/to these areas, which could have resulted in including air travellers from zones outside the calibrated rail catchment areas, thus leading to more air demand overall.

b. The low level of detail in the LAD-based JtW compared to its MSOA-based counterpart and the fact that the estimated rail demand is underestimated by 3.28% as reported in Table 6.

Table 6: Modelled and observed rail and air mode share across specific routes

Route	Modelled		Provided by Lumo	
	Rail	Air	Rail	Air
London - Edinburgh	41%	59%	50%	50%
London - Newcastle	76%	24%	80%	20%
London - Glasgow	23%	77%	26%	74%

A.1.3 Emissions modelling

To model the avoided emissions of annual travel for each O/D pair bidirectionally, it was necessary to calculate the difference between the emissions generated by a single Lumo trip and the average emissions associated with that same a trip in a baseline scenario where Lumo services did not exist, before scaling to a year of demand. The total avoided emissions for Lumo services over a year could then be calculated by summing the total annual avoided emissions for each O/D pair (Figure 11).

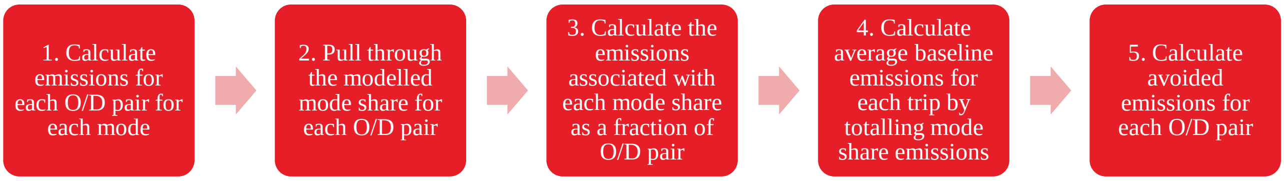

Figure 11: Emissions modelling process

Our approach to modelling the baseline scenarios was underpinned by a key assumption; in the absence of Lumo services, those Lumo journeys would instead be distributed across transport modes in a ratio reflecting our modelled mode share. Consequently, to calculate the avoided emissions for a trip (e.g. London to Edinburgh), it is necessary to calculate the emissions generated by a single journey for that trip via each possible mode, before taking a weighted average for the trip based on mode share. This modelling approach was executed across five stages described hereafter.

A.1.3.1 Calculate emissions for each O/D pair for each mode

For all eleven O/D pairs, the emissions for a journey via car, coach and rail were calculated by multiplying journey distances by the combined value of relevant Scope 1 and 3 emission factors. These emission factors are detailed in Table 7:

Table 7: Emission factors used for transport modes within the avoided emissions modelling

Transport Mode	Emission Scope	Emission Factor ($kgCO_2e$/passenger.km)	Description	Source
Car	Scope 1&2	0.1666	'Business travel-land: Car size - Average car; Fuel type – Unknown'	DESNZ Conversion Factors 2023[10]
	Scope 3	0.0437	'WTT pass vehs & travel- land: Car size - Average car; Fuel type – Unknown'	DESNZ Conversion Factors 2023
Rail	Scope 1&2	0.0295	Emission factor specific to LNER train services. This approach was selected over the application of an emission factor for average national rail as it was recognised that LNER trains have a higher electrification rate and thus a lower emissions intensity than the national average.	Power of One" Campaign' (2022) report from UCL MaaSLab[11]
	Scope 3	0.0090	'WTT travel-land National rail'	DESNZ Conversion Factors 2023
Coach	Scope 1&2	0.0272	'Business travel-land: Bus Type – Coach' for all O/D pairs except Newcastle-Morpeth	DESNZ Conversion Factors 2023
		0.1184	'Business travel-land: Bus Type – Local bus (not London)' for Newcastle-Morpeth selected due to local transport network characteristics	
	Scope 3	0.0066	'WTT pass vehs & travel- land: Bus Type – Coach' for all O/D pairs except Newcastle-Morpeth	DESNZ Conversion Factors 2023
		0.0289	'WTT pass vehs & travel- land – Local bus (not London)' for Newcastle-Morpeth to reflect local transport network	

To calculate the air transport emissions for each route that could be serviced by airports, including across the five different London airports, an approach was selected to align with that applied in the Lumo Carbon calculator prepared by Arup for Lumo. The ICAO Carbon Emissions Calculator[12] was used to extract values for passenger $kgCO_2$/pax/leg, which when multiplied against the provided distance (km) values, produced

[10] DESNZ. (2023). Conversion factors 2023: full set (for advanced users) – updated 28 June 2023.
[11] Chaniotakis. E.M., Johnson. D.T. & Ekins. P. (2022). Evaluating the LNER "Just One Journey" Campaign.
[12] ICAO (2023). ICAO Carbon Emissions Calculator.

Scope 1 $kgCO_2e$/passenger.km emission factors. To account for the effect of Radiative Forcing (RF), where emissions at higher altitudes result in higher global warming potential, a RF conversion factor was applied to these air travel emission factors. This conversion factor was sourced using the ratio between the *DESNZ Conversion Factors 2023* 'Business travel- air: Domestic' emissions factors with RF to those without RF. The RF converted Scope 1 emission factors were then combined with a Scope 3 emissions factor, the *DESNZ Conversion Factors 2023* 'WTT-business travel- air: Domestic' conversion factor, to produce the final emissions factors. These emission factors were then multiplied by the airport-to-airport distances to calculate the emissions for each airport-to-airport trip. Where multiple airports could serve a given route, a weighted average of the distance was used.

A.1.3.2 Pull through the modelled mode share for each O/D pair

To match with the emission estimates for each trip, it was necessary to pull through the relevant mode share values across each of the four modes of transportation. This was based on the outputs of the baseline emissions modelling process described in the previous section and returned a table of mode share percentages for each route.

A.1.3.3 Calculate the emissions associated with each mode share as a fraction of each O/D pair

For each trip, the estimated emissions across all transportation modes were then multiplied against their respective modelled mode share percentages. This produced values for the portion of baseline scenario trip emissions contributed to by each transportation mode for all eleven O/D pairs.

A.1.3.4 Calculate average baseline emissions for each O/D pair by totalling mode share emissions

The total baseline scenario emissions values were derived by summing the contributions from each mode. This was done for each O/D pair, producing an average emissions value across from those available for each mode, weighted by the mode share split predicted for the route.

A.1.3.5 Calculate avoided emissions for O/D pair

Avoided emissions values were then generated for each O/D pair by calculating the difference between the baseline scenario journey emissions and the respective real-world Lumo journey emissions. The Lumo trip emissions data was sourced from the Lumo Carbon Calculator, which derived an emissions factor for Lumo travel based on electric current for traction data. To calculate the total avoided emissions for FY23, the kgCO2e/trip values for each O/D pair were multiplied by the respective total number of journeys taken during the period. To support reporting, results were broken down into more generalised trip reporting groups based on the regions served by Lumo. These regional grouping are Southeast England (SE), Northeast England (NE) and Scotland (Table 8). The grouping of these baseline emissions was done by calculating a weighted average based on annual trip demand between the origin/destination pairs.

Table 8: Mapping O/D pairs to regional groupings

Regional grouping	O/D pair
SE to NE	London to Newcastle London to Morpeth Stevenage to Newcastle Stevenage to Morpeth
SE to Scotland	London to Edinburgh London to Glasgow Stevenage to Edinburgh
Intraregional	Newcastle to Morpeth
NE to Scotland	Newcastle to Edinburgh Newcastle to Glasgow Morpeth to Edinburgh

A.1.4 Assumptions and limitations

As suggested in the Framework, the assumptions and limitations of the approach taken in this assessment are detailed in this section. First, the core assumptions that underpin the analysis are described, before other assumptions used in the modelling are noted.

A.1.4.1 Core assumptions

- For the Baseline scenario, we are assuming that individuals initially travelling with Lumo, will shift to other modes in the absence of Lumo based on the modelled mode share across rail, car, air and coach/bus. As a result, our findings currently do not reflect the complexity which might be found in a formal choice model.
- Trips are described based on the dominant mode used, we do not account for multi-modal trips or modes used to access or egress from the stations or airports.
- For airports with no additional information on the origins/destinations of terminating passengers, air transport for a specific O-D was attributed to the city the airport serves (Newcastle, Edinburgh and Glasgow).
- Re-projected commuting demand from 2011 to 2023 was based on the official NTEM forecasts for population and employment growth. Although our chosen approach respects the observed mobility patterns per mode and O-D pair, the base of our analysis is still based on forecasted numbers instead of observed data. The other alternative, however, of using the recently published JtW of Census 2021, could pose more problems due to the period that was collected (during the pandemic).
- We have included the main Lumo O-D pairs which account for the 99.3% of observed Lumo demand, in total. Some less frequent routes were excluded.
- Journey purpose shares for non-commuting trips were based on a pre-covid period of NTS. It should be acknowledged that NTS, although representative enough, is still a survey and as a result it might underrepresent trips of certain purposes between specific areas.
- Because sample size of trips between Local Authorities in NTS was small, it was decided to use trips between the respective regions to derive the purpose shares. The only exception was the intraregional route of Newcastle-Morpeth for which the trips between the respective Local Authorities were used as it provided sufficient sample size.
- The purpose shares between regions (and between Newcastle-Morpeth) from the NTS were not segmented by mode. Therefore, potential discrepancies of trip purposes among rail, car and bus were not taken into account.

A.1.4.2 Other modelling assumptions

- To calibrate modelled rail journeys from the analysis based on Census Data and the NTS, annualisation factors developed for each route were used to convert estimated daily rail demand to annual demand values. These values were based on rail demand data for the reporting period provided by Lumo.
- It is assumed that all alternative rail journeys on the Lumo route are served by LNER, and an emissions factor for LNER was used for calculating rail emissions within the baseline scenario.
- The JtW matrix does not differentiate between bus and coach. As a result, it is assumed that long-distance travel is performed by coach, whereas specifically for the Newcastle to Morpeth route, it was assumed that travel would be via local bus services.
- Trips for car drivers and car passengers from the reprojected JtW matrix were added together to find the total car demand used to define the mode share in the baseline scenario.
- We assume average load factors on all services across all modes.

A.2 Acronyms

BAU	Business-as-Usual
CAA	Civil Aviation Authority
CDP	Carbon Disclosure Project
DESNZ	Department of Energy Security and Net Zero
DfT	Department for Transport
ESG	Environmental, Social, and Governance
GLA	Greater London Area
LAD	Local Authority District
IPF	Iterative Proportional Fitting
JtW	Journey to Work
MSOA	Middle Super Output Area
NE	North East
NTS	National Travel Survey
O/D Pair	Origin/Destination Pair
ONS	Office for National Statistics
SE	South East
WTT	Well-to-Tank

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