elementenergy

Decarbonising the Scottish Transport Sector

Final Report

for

Transport Scotland

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Executive Summary

In 2019, Scotland introduced a new set of economy wide emission targets to reflect the updated advice of the UK Committee on Climate Change. This led to Scotland setting a target to reduce emissions to net-zero by 2045, with the interim target to reduce emissions by 75% between 1990 and 2030 and 90% by 2040. Having set these new emission targets, Transport Scotland commissioned Element Energy to understand the policy outcomes Scotland needs to achieve, in terms of the introduction of zero-emission vehicles and changes in transport behaviour, to meet these emission targets in the transport sector.

This study aimed to understand the range of policy outcomes required by Scotland through detailed modelling of the vehicle stock turnover and transport behaviour across several Policy Scenarios (PS). The study focused on 4 PS as summarised below. For each of these PS, a sensitivity was run to understand the potential impact of autonomous vehicles, but it was clear that autonomous vehicles will not enter the fleet in large volumes until most new vehicles are zero-emission and so the emissions impact will be limited. The initial finding showed that only PS3 was able to meet Scotland's emission targets, with the other PS falling well short. The decision was therefore taken to focus on PS3 in this analysis and reporting.

- **PS0**: Business as Usual, transport change based on existing policy measures.
- **PS1**: Rapid introduction of low and zero-emission technologies. Transport demand follows existing Transport Scotland and UK Department for Transport growth projections.
- **PS2**: Rapid introduction of low and zero-emission technologies. Passenger and freight kilometres travelled remains the same as PS1, but vehicle kilometres travelled are reduced through modal shift from cars and planes to public and active travel modes.
- **PS3**: Rapid introduction of low and zero-emission technologies. Passenger, freight, and vehicle kilometres travelled are reduced through modal shift from cars and planes to public and active travel modes, and reduced travel demand through trip shortening (facilitated through measures such as 20-minute neighbourhoods) and trip avoidance (facilitated through measures such as teleconferencing).

Limited progress has been made to date in reducing emissions from the Scottish transport system as improvements in vehicle efficiency have been largely offset by increasing demand. As a result, domestic transport emissions have only fallen by 2-3% since 1990, while international

transport emissions have increased by over 40% since 1990, highlighting the major challenge ahead to meet Scotland's new emission targets. Although Scotland's economy-wide emissions targets are 75% reduction by 2030, 90% reduction by 2040 and net-zero by 2045, from a 1990 baseline, analysis conducted by the Scottish Government using the TIMES model has assigned the transport sector its own emissions envelope of 56% reduction by 2030, 70% reduction by 2040 and net-zero by 2045, from a 1990 baseline[1].

Figure 1 shows the progress made towards these transport emission targets in PS3 for 2030, 2040 and 2045. The analysis has found that meeting the 2030 target is the most challenging because of the short timeframes involved, but it is recommended that special effort should be made to hit this target as the cumulative impact of emissions means meeting earlier targets are especially important. However, PS3, which includes high zero-emission vehicle uptake, major modal shift to more efficient transport modes, such as buses and rail, and a significant reduction in transport demand, is able to meet all three targets. This clearly demonstrates that a pathway which relies only on the introduction of zero-emission vehicles will fail to meet the emission targets and that major changes in the way people travel will be needed, alongside technology, if Scotland is going contribute its fair share of emission reductions to avoid the worst impacts of climate change.

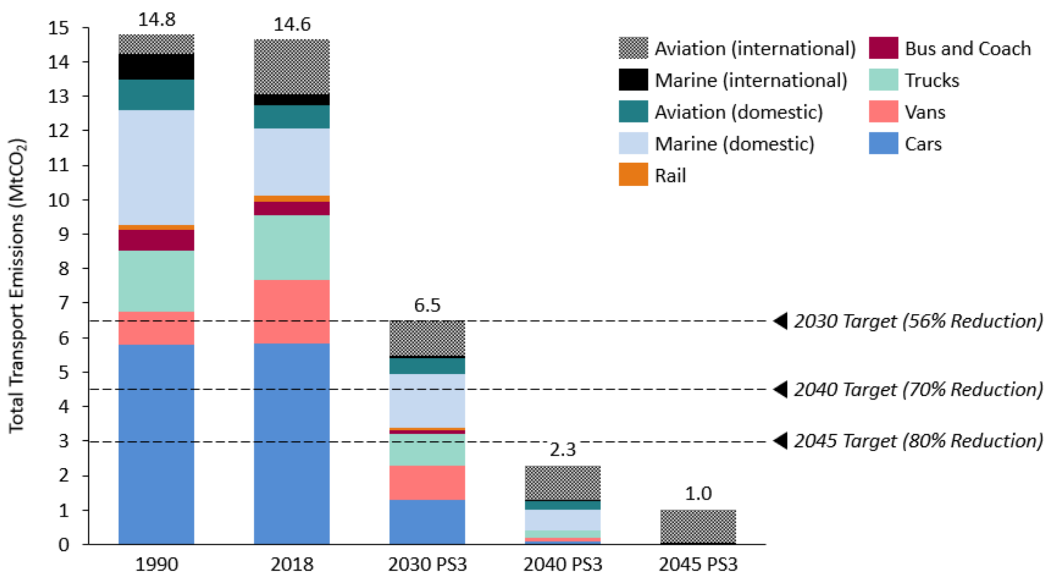

Figure 1: Progress made towards Scotland's transport emission in PS3 for 2030, 2040 and 2045.

[1] TIMES calculates these emission envelopes as the emission reductions needed before emission offsetting. These emission reductions must therefore be achieved through direct emission reductions alone.

Enacting PS3 will have a major impact on the lives of everyone in Scotland. It is the most challenging of the scenarios modelled in this report to enact in the real-world and will require the greatest commitment and support of policy makers. However, unlike the technology-focused scenarios (PS0 and PS1), PS3 presents the opportunity to achieve far more than just reducing transport emissions. If the policies needed to achieve PS3 are well designed they will also improve public health, access and mobility for disadvantaged groups, urban environments, social inclusion, work flexibility, and access to green spaces, while also reducing congestion and road fatalities.

While delivering PS3 can provide wider benefits to the Scottish people, a just transition, which is at the core of what the Scottish Government has set out to achieve (see Scottish Government, 2021, A National Mission for a fairer, greener Scotland), is not ensured. To achieve a just transition policy must be carefully designed to ensure equal access to zero-emission vehicles, and to drive decarbonisation in all sectors (car, van, bus, truck etc.) fairly so that no sector, or its users, are unfairly burdened by the cost of decarbonisation. For example, the bus sector is on the verge of a very quick decarbonisation transition as zero-emission vehicles are introduced but the aviation sectors will not achieve significant emission reductions at anywhere near the same rate, in the short term, due to a lack of technology readiness. Regular flying is a privilege of the richest people in society whereas regular bus use is much more common in poorer demographics. Governments must ensure that these difference in technology readiness do not lead to the poorest in society paying for the early decarbonisation of transport while richer groups do not pay the full economic cost of their pollution until much later in the transition. For a just transition all sectors and all users must do their fair share to pay for the costs of the transition. This ethic, along with a technical analysis of the technology readiness and behavioural change possibilities has been at the centre of this works effort to divide up the Scottish transport emission envelope between the transport sectors.

Enacting PS3 will require policies and budget from across multiple Scottish Government departments but also from the UK government (e.g. for car tax) and from wider regional (European) and global political agreements (e.g. for international aviation and shipping) to achieve, making good planning and collaboration an important prerequisite for its success, but also posing a risk to Scotland's ability to meet these climate targets if other countries do not step up and show the same world leading ambition as Scotland.

The main policy outcomes for PS3 are set out below. These are Scotland wide outcomes, but we recognise that the response across urban and rural areas is likely to be very different meaning technology and behavioural change outcomes will need to be adjusted to match the needs and opportunities of different groups.

Vehicle Technology Policy Outcomes

- End the sale of fossil fuel powered cars and vans in 2030.
- Phase out the sale of the largest most polluting cars between 2020-2030.
- End the sale of fossil fuel powered buses in 2025 and start a retrofit program for older buses to install zero-emission powertrains.
- End the sale of fossil fuel powered trucks in 2035.
- Allowing existing UK policies to drive the uptake of biomethane powered trucks for the highest annual mileage applications.
- Ensure all trucks are retrofitted with the latest low aerodynamic and rolling resistance features by 2030.
- End the use of fossil fuelled vehicles on Scottish roads in 2045 (following the sales targets presented in the earlier points will remove almost all fossil fuel powered vehicles from the fleet through natural fleet turnover by 2045. A five-year extension could be offered to some important fleets based in England).
- Replace all diesel trains with hydrogen or electric trains by 2035.
- Support the development, production, and certification of net-zero synthetic aviation drop-in fuels early in the 2020s, targeting a minimum of 10% Sustainable Aviation Fuels (SAF) blending by 2030, and push for their widescale rollout across Europe and globally.
- Support the development of zero-emission ship powertrains in the 2020s, complete trials of zero-emission ships by 2030 and end the sale of fossil fuel powered ships and begin retrofitting existing ship powertrains from the early to mid-2030s.

Behavioural Change Policy Outcomes

- The main transport mode for people moving within and between the urban regions of Scotland (this is assumed to include Edinburgh, Glasgow, Dundee, Aberdeen, and the satellite towns/villages that surround them) must switch from private cars to public/active and shared transport modes over the next decade.
- Walking must become the preferred mode of transport for short journeys and cycling (bikes and e-bikes) must be a viable mode for both urban and inter-urban journeys.

- The use of active, public, and shared transport must be encouraged and facilitated through excellent infrastructure, Mobility as a Service (MaaS) and preference in all transport and land-use planning decisions.
- The modal shift, along with destination shifting, journey shortening (facilitated through 20-minute neighbourhoods), journey avoidance (facilitated by teleconferencing) and car sharing, set out in the first three bullet points, must achieve a 20% reduction in the number of car kilometres travelled across the whole of Scotland between 2019 and 2030.
- This in turn will require a major increase in bus, coach, and train numbers. This needs to be overseen by government to ensure everyone has access to the public transport network but will partially be driven by industry as higher ridership rates improves the business case to provide the service.
- Shift the purchase of BEV and FCEV towards high mileage users (e.g., ensure that all taxi, private hire, and company car fleets are BEV/FCEV only by 2030).
- Increases in vehicle demand caused by the decreasing cost of electric fuels must be mitigated through a policy, such as road user charging, which brings transport costs per km back up to current fossil fuel per km prices for driving.
- Limit the growth in van demand to 10% between 2019 and 2030, reducing demand by 7% in 2030 compared to the BAU scenario.
- 23% of freight goods moved by road must be shifted to rail and ships by 2030 (this is expected to be predominantly on longer routes and is equivalent to all road freight moved over 400km, although exact routes shifted to rail will depend on infrastructure). This means improving the freight train links between Scotland and England to allow them to take more of the cross-border freight movements and upgrading Scottish ports to allow greater freight movement capacity.
- Reduce truck tonne km by 15% by 2030 through a range of efficiency measures such as reducing food waste, improving product lifetime, optimising goods to vehicle allocation across and between fleets (backhauling, co-loading, physical internet).
- The emissions from the movement of fossil fuels by ship from Scotland to remote areas of the world such as South East Asia is assumed to reduce close to zero by 2030 through lower levels of production, decreases in exports and/or reduced carbon intensity of transportation.
- Emissions from domestic and international aviation need to fall by 33% between 2019 and 2030, driven by a mix of SAF and a reduction in total flight kilometres travelled.

As a follow on to the core PS, the study also considered the impact of the COVID-19 pandemic on the emission trajectory of PS3. Given the high uncertainty in the long-term impacts of the pandemic, 4 COVID scenarios were modelled reflecting different durations of COVID impacts and different types of government/industry response, as summarised in Figure 2.

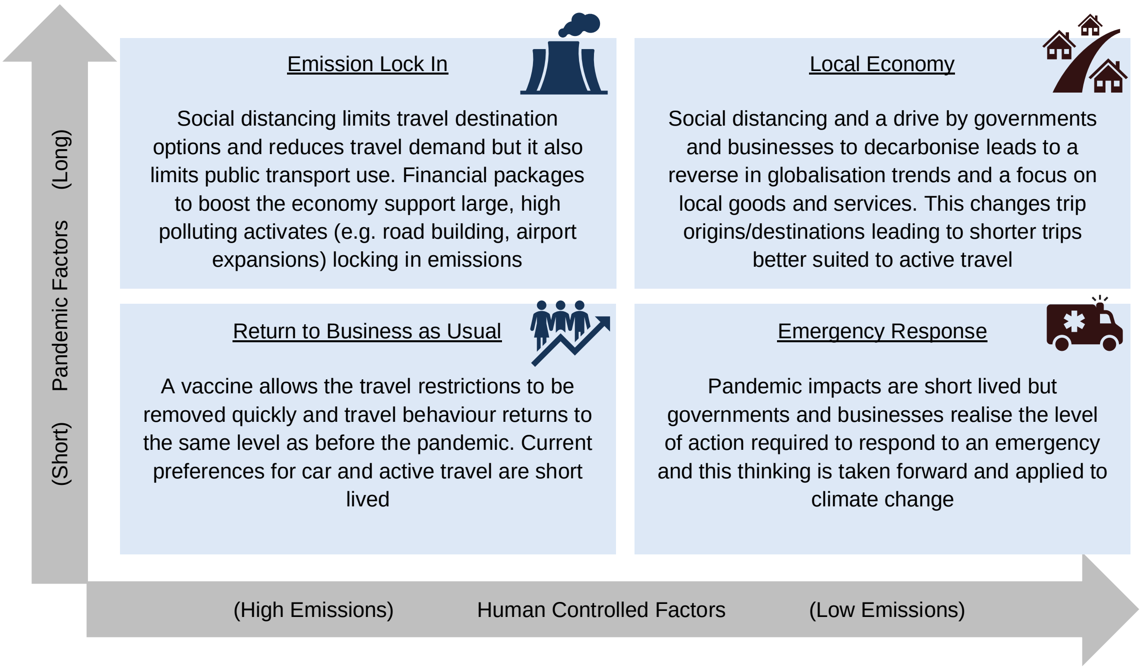

Figure 2: COVID scenario summary

The main finding from this analysis was that while the immediate impact of the pandemic has been very large, the longer-term impacts, which might still be felt by 2030, are small when compared to the level of economy wide change needed to meet Scotland's emissions targets (see Figure 3). One of the key reasons why the pandemic is not expected to radically increase or decrease emissions is because it is very unlikely that we transition to a future where predominantly emission positive or emission negative changes prevail. Instead, what we see is that most changes that are positive for emissions are likely to coexist with changes that are negative for emissions (e.g., the pandemic may increase the number of people working from home, especially in higher income sectors, reducing commuting trip frequency; however, at the same time these people may choose to move further away from work looking for cheaper housing and more space. This move away from urban centres will lock in car dependency and longer trip distances not just for commuting trips, but for all trips, potentially offsetting any emissions benefits) meaning the net emissions impact of the pandemic in 2030 is smaller than first expected. While the emissions difference between the highest and lowest emissions scenario presented in Figure 3 is small relative to the level of disruption caused by the pandemic, the difference is still significant as all measures have been employed to meet the targets leaving no additional measures for

Transport Scotland to employ if activities such as road building and airport expansions lock in additional emissions.

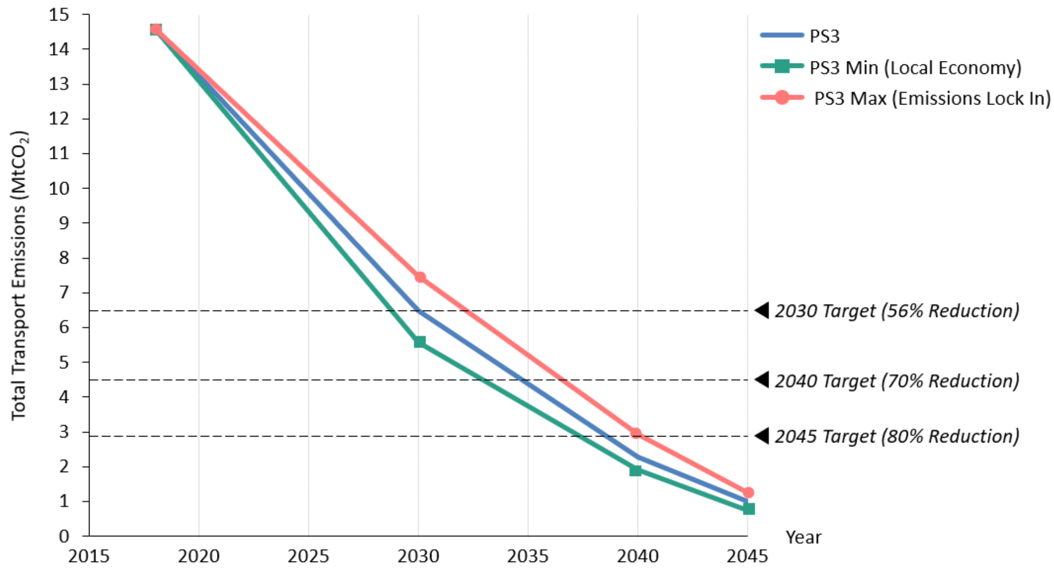

Figure 3: COVID scenarios emissions impact

The difference in emissions between the scenarios in Figure 3 are predominantly driven by two key factors. Firstly, all the scenarios meet the fossil fuel powered car, van, and truck phase out dates proposed earlier except Emissions Lock In where phase out dates slip due to increased industry lobbying aimed at weakening environmental standards on the grounds of falling profits and resulting job losses. This could for example happen if Scotland follows the UK's position and allows PHEV car and van sales until 2035, the UK government is lobbied to allow PHEV with low all-electric range, and no incentives are introduced to encourage users to plug-in and charge the vehicles. These factors result in PHEV having a similar emissions impact to pure petrol and diesel vehicles and is roughly equivalent to Scotland delaying the 2030 target proposed here by a couple of years.

Secondly, the largest impact of the pandemic is expected to be the impact on spending. Many consumers will be worse off after the pandemic, decreasing spending on activities such as shopping, which will reduce the emissions from these activities. At the same time, Government will be investing in the economy to boost growth and will be encouraging industry to do the same. If these investments focus on activities such as road building, airport expansions, out of town shopping centres, car centric housing estates, and North Sea oil and gas extraction then the long-term impact of the pandemic will have been to increase emissions and make meeting the decarbonisation target much harder. If, on the other hand, investments focus on activities such as rail infrastructure, pavements, cycle lanes, bus lanes, zero-emission public transport vehicles, city centre revitalisation, improving and repurposing existing building to provide local services, and freight urban consolidation centers then the long-term impact of the pandemic will have been to decrease emissions and accelerate the decarbonisation transition.

This study only focuses on the emissions of the different scenarios and is unable to calculate the costs of the different scenarios because the study only looks at policy outcomes and does not set out specific policy packages; therefore, the cost of the policies to government cannot be calculated, neither can the cost of the scenarios to the general public or the wider economy. However, Element Energy and Cambridge Econometrics have completed a study for Climate X Change on the economic impacts of Ultra-Low Emission Vehicle (ULEV) adoption in Scotland[2]. The study concluded that the overall economic impact of a switch to ULEV vehicles will be positive for Scotland, with the jobs and revenue lost from current vehicle production and maintenance, petrol station operation and fossil fuel extraction/distillation and distribution more than offset by new jobs and revenue produced from ULEV production and maintenance, ULEV infrastructure rollout and ULEV fuels production.

Transport Scotland with the support of the whole Scottish Government, UK Government, Scottish businesses, and the whole Scottish population will have to achieve all the policy outcomes and behavioural changes listed above to meet the emission targets. This report provides policy outcomes or targets, not policies, the next step following on from this work is for Transport Scotland, supported by wider Scottish and UK Government, to use these findings and other research to design appropriate policies.

As is highlighted in several places in this report Scotland's efforts to decarbonise are not isolated but are deeply impacted by efforts made internationally to supply zero emission vehicles and tackle emissions from international travel. Scotland's transport decarbonisation pathway is additionally impacted by that of the UK as a number of key policy levers (including relevant taxation) are reserved to the UK Government. However, the level of climate ambition between Scotland and the UK as a whole are not equal. The UK aims to reduce emissions by 68% between 1990 and 2030 and reach net zero by 2050. Scotland by contrast aims to reduce emissions by 75% between 1990 and 2030 and reach net zero by 2045. These differences naturally require stronger policy and greater ambition in Scotland compared to the UK as a whole. At a UK level the Transport Decarbonisation Plan (TDP) was published in July 2021 to set out the

[2] Study "Identifying the Economic Impacts from ULEV Uptake" currently under review by Climate X Change before publication

pathway to decarbonising transport. This report is very welcome to bring greater clarity to the UK wide efforts; however, it is clear that this study and the TDP differ significantly in respect to the need for behaviour change. In this study major changes in travel behaviour are a necessary part of reducing emissions and a positive step in improving transport equity in Scotland, this contrasts with the TDP statement “It’s not about stopping people doing things: it’s about doing the same things differently. We will still fly on holiday, but in more efficient aircraft, using sustainable fuel. We will still drive on improved roads, but increasingly in zero emission cars.”, which favours a more status quo approach.

We have studied the TDP to understand how the two reports can come to such different conclusions on the need for behaviour change and we believe it is because very different levels of emission reductions will be achieved in each case in 2030 (2030 is a key date as the cumulative nature of CO2 build up in the atmosphere makes early carbon reductions much more important in reducing the impacts of climate change than later emission reductions made in the 2030s and 2040s). The TDP scenarios deliver between a 5% and 40% reduction in domestic and international transport emissions between 1990 and 2030, with a central scenario at 20%. Our analysis of the TDP suggests that the policies actually committed to in the TDP are likely to deliver towards the bottom end of this spectrum. By comparison this study targets a 56% reduction in domestic and international transport emissions between 1990 and 2030, requiring much greater ambition in technology and behavioural change policy, but especially in behavioural change policy as the opportunity to significantly shift the technology of whole fleets in 2030 is rapidly closing.

Contents

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Acronyms

ADL	Alexander Dennis Ltd.
CalMac	Caledonian MacBrayne
CAV	Connected and Autonomous Vehicles
CCC	Committee on Climate Change
CCUS	Carbon Capture, Utilisation and Storage
CPT	Confederation of Passenger Transport
DfT	Department for Transport
FMEL	Ferguson Marine Engineering Limited
IMO	International Maritime Organisation
MaaS	Mobility as a Service
MagTec	Magnetic Systems Technology
OEM	Original Equipment Manufacturer
PS	Policy Scenario
TCO	Total Cost of Ownership
ULEB	Ultra-Low Emission Bus
ULEV	Ultra-Low Emission Vehicles

1 Introduction

1.1 Policy Context

Scotland has a strong history of demonstrating political commitment to tackling climate change. The Climate Change (Scotland) Act 2009 set a target to reduce emissions by 80% between 1990 and 2050, which was strengthened by the Climate Change (Emissions Reduction Targets) (Scotland) Act 2019 which commits to achieving a 75% reduction, relative to 1990, by 2030, and net-zero by 2045. Analysis conducted by the Scottish Government using the TIMES model has assigned the transport sector its own emissions envelope of 56% reduction by 2030, 70% reduction by 2040 and net-zero by 2045, from a 1990 baseline. These TIMES envelope emission allowances are the emission reductions targeted in this study. Under Scotland's climate change legal framework these emission reductions must be met directly through technology or behavioural change with further emission reductions achieved through carbon offsetting on top of these emission envelopes. This means carbon offsetting and emission trading are factored in outside of the emission envelope on which this study focuses and are therefore not considered here. Scotland's new climate goals are some of the most ambitious targets in the world and meeting them in the transport sector will require significant changes to the technology that powers vehicles and the modes of transport that are used.

In 2018, transport (including international aviation and shipping) accounted for 36% of Scotland's total greenhouse gas emissions (see National Atmospheric Emissions Inventory, 2019, Devolved Administrations – Greenhouse Gas Reports). The Scottish Government has already pledged to phase out the need for purchase of petrol and diesel cars by 2030, which will be aided by the UK Government's announcement to bring forward the UK-wide ban on petrol and diesel car sales to 2030 and PHEV to 2035. Scotland has also committed to decarbonising passenger rail services by 2035 and to decarbonising scheduled flights within Scotland by 2040. However, it is clear that actions taken to date are not sufficient to meet the net-zero and intermediate targets and that a new, broader set of policies, that focus on managing travel demand and not just the introduction of new powertrains, are needed if these targets are to be met.

1.2 Overview of Work

When first started in 2019, this was one of the first studies to map a transport decarbonisation pathway for emission targets as ambitious as those in Scotland. It was, therefore, unclear how much technology and behavioural change would be needed to meet the emissions targets. To understand this the study started by modelling seven scenarios to understand the impacts of different levels of ambition for:

1. Low/zero emission vehicle uptake.
2. Modal shift, e.g., from cars and planes to walking, cycling, buses, and trains.
3. Reduced demand for travel through actions such as land planning for 20-minute neighbourhoods leading to trip shortening and trip avoidance through teleconferencing to avoid business trips.

Figure 4 outlines the seven scenarios analysed. The first scenario, Policy Scenario 0 (PS0), reflects a Business as Usual or Baseline case showing the impact of policies currently enacted in Scotland.

In each of the Core Scenarios zero-emission vehicles are introduced as quickly as global vehicle supply chains will allow. This means that only one zero-emission vehicle uptake curve is considered for each vehicle type (cars, vans, buses etc.). The three Core Scenarios are differentiated by the level of transport demand. Policy Scenario 1 (PS1) allows total passenger and freight kilometres to grow in line with the business-as-usual case. Policy Scenario 2 (PS2) allows passenger and freight mobility to continue in line with the business-as-usual case but makes use of modal shifting, to more efficient transport modes, to deliver a reduction in total vehicle km travelled. Policy Scenario 3 (PS3) combines the modal shift impacts from PS2 with an absolute reduction in the demand for passenger and freight mobility. Three sensitivity scenarios (PS1S, PS2S, PS3S) were also modelled to understand the potential impact of the introduction of autonomous vehicles on the core scenario emissions.

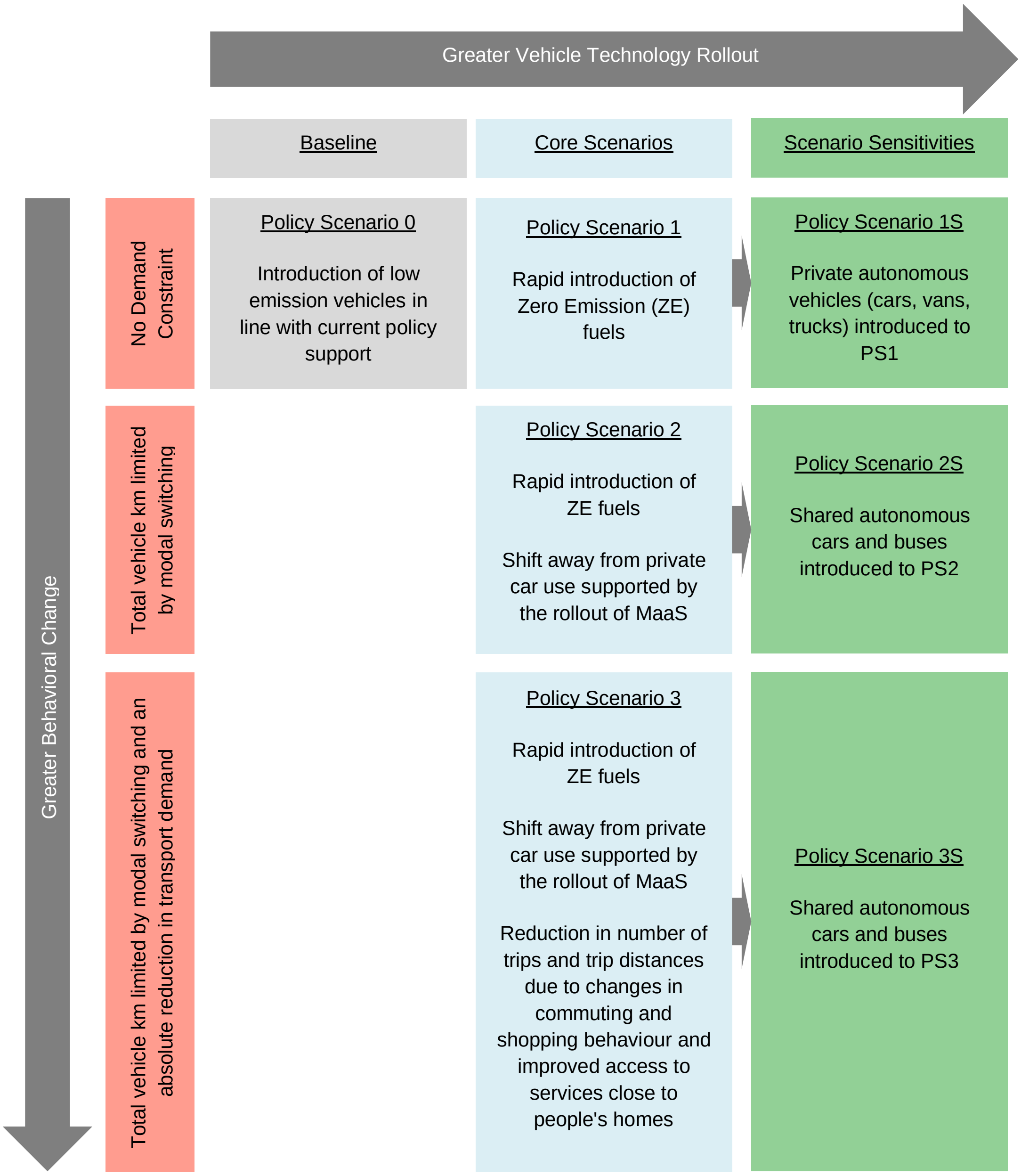

Figure 4: Detailed breakdown of policy outcome scenarios

Following the completion of the first 7 scenarios the COVID 19 pandemic impacted travel around the world and Transport Scotland commissioned Element Energy to complete several additional scenarios to understand the impact of the pandemic on the original scenario results.

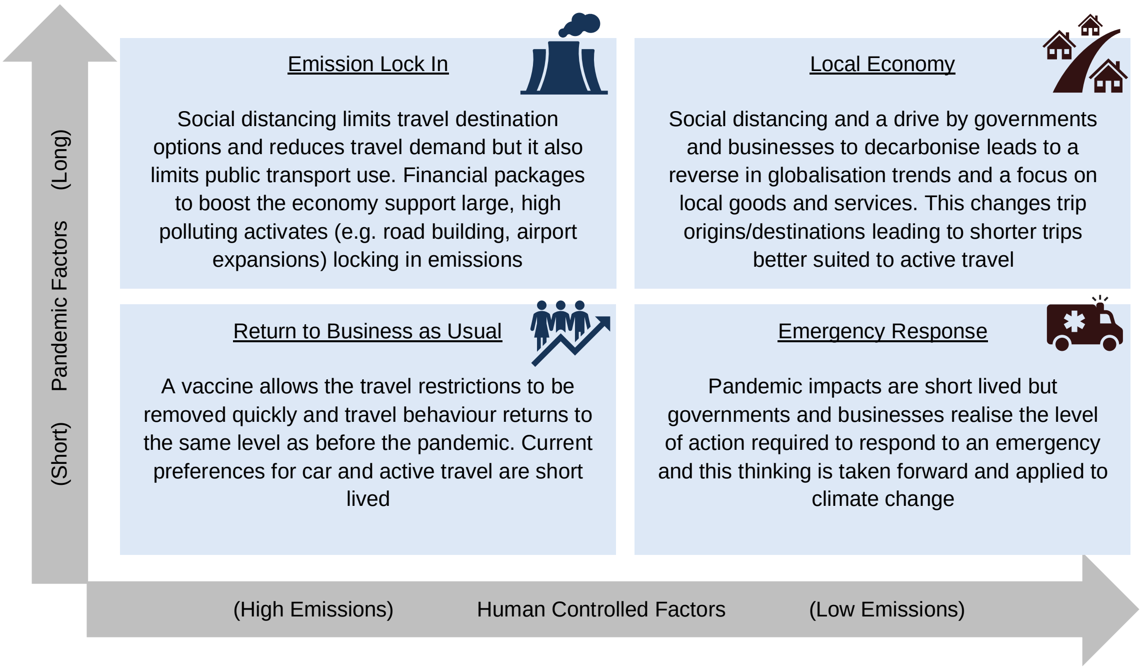

Figure 5: Additional COVID 19 policy outcome scenarios

1.3 Scenario Findings and Impact on the Report

The results from the seven original scenarios and the four COVID scenarios have shaped our view of the challenge of meeting Scotland's emission targets and the narrative presented here. The key findings and their impact on the report focus include:

1. **Scotland's 2030 target is the most challenging**. The short timeframe and the immaturity of much of the technology needed to meet the 2030 target make this target very challenging to deliver. However, once the hard work has been completed and the right policies put in place in the 2020s Scotland will be in an excellent place to meet the 2040 and 2045 target. **As a result of this the report often focuses on the 2030 target in the discussions as this target often defines the options available in Scotland's decarbonisation transition.**
2. **All the types of technology and behavioural change actions studied are needed to meet the Scotland's emissions targets**. This means that of all the seven baseline scenarios studied only PS3, where rapid zero-emission technology change and modal shift and travel demand reduction are achieved, meets Scotland's emission targets. **Therefore, this report only presents the assumptions and results for PS3 in order to give the reader a clear message of the policy outcomes required.**
3. **The decarbonisation ambition across vehicle types (car, van etc.) is a balance that tries to treat all sectors fairly**. There is no

physical constraint defining the level of decarbonisation ambition across different vehicle types. Instead, the report tries to set a fair level of ambition across vehicle types based on zero-emission technology readiness and behavioural change options. **Given that this breakdown has as much of an impact on each sector as the overall target a significant proportion of this report is given over to setting out the basis for the breakdown in detail (see Chapter 2)**. Each sector might prefer a different breakdown which requires less change from them, but it is always worth noting that relaxing the ambition for one sector requires additional ambition from other sectors. We believe we have pushed the level of ambition to its maximum in each sector suggesting there is very little room for rebalancing the ambition across sectors.

4. **The introduction of autonomous vehicles has a limited impact on emissions**. The scenario sensitivities looking at the introduction of autonomous vehicles had a significant impact on energy demand and therefore system wide emissions but very little impact on the tailpipe emission in transport. This was because autonomous vehicles did not enter the fleet in numbers until the 2030s at which point most new vehicles are assumed to be zero-emission. **Therefore, the report does not cover these sensitivity scenarios in any detail**.
5. **Only the more extreme COVID 19 scenarios show a significant emissions impact. These scenarios are therefore the focus of the discussion in this report.**

1.4 Report Structure

Chapter 1, Introduction. Sets out the context for the work done and explains the reasoning for the report structure/findings presented.

Chapter 2, Policy Scenario 3: Scenario Building and Results. Describes the technology and behavioural changes for each vehicle type (cars, vans etc.) in PS3, needed to meet Scotland’s emission targets. Presents the PS3 results and discusses their impacts on delivering decarbonisation in Scotland.

Chapter 3, COVID Scenarios: Scenario Building and Results. Describes the COVID scenarios in detail and presents the scenario results with a discussion of their impact on delivering decarbonisation in Scotland.

Chapter 4, Scenario Implications for Cost and Equity. Discusses the non-emission impacts of the scenarios including the impact on vehicle cost and social equity.

Chapter 5, Recommendations. Details recommendations for achieving Scotland's emission targets considering the current barriers to zero-emission vehicle uptake, behavioural change, and the Scottish specific barriers of policy control.

Chapter 6, Conclusions. Outlines the project conclusions and implications.

2 Policy Scenario 3: Scenario Building and Results

This chapter provides a high-level overview of the key technology and behavioural change assumptions and policy outcomes required across different modes in order for Scotland to meets its emission target in 2030, 2040 and 2045. The chapter starts with a summary of the of different levels of ambition modelled across sectors to provide context on why the policy outcomes have been chosen.

2.1 Overview of Policy Outcomes

This section summarises all the policy outcomes. The policy outcomes have been set with the aim of achieving ambitious but fair levels of change in each transport sector. Each sector has been reviewed, and technology and behavioural change outcomes assigned based on the state of decarbonisation technology in the sector today and easy of opportunities to reduce emissions through behavioural change. This means some sectors such as cars, with advanced zero-emission powertrain technology and multiple options for behavioural change, achieve most of the decarbonisation over the next decade, while other sectors with immature decarbonisation technology and limited modal shift or demand reduction options, such as international marine, are expected to achieve much less decarbonisation in the next decade, but the targets for both these sectors are equally ambitious given current opportunities. The full list of policy outcomes is summarised in Table 1 below.

Table 1: Summary of policy outcomes for Policy Scenario 3

Sector	Ambition	Technology Policy Outcome	Behaviour Policy Outcome
Car	**Technology** - Ambitious change but very achievable given the similar UK wide target[3] **Behaviour** – Very ambitious change but possible given the urban focus of the Scottish population and the inefficiencies in private car travel. Main barriers are expected to be public response rather than physical implementation	End the sale of petrol, diesel, hybrid, and plug-in hybrid cars by 2030. Increase the sale of small cars from 40% of sales today to 60% of sales in 2030, with the increased achieved through a reduction in the sale of large salon and SUV cars	Reduce car kilometres by 20% between 2019 and 2030. Shift the purchase of BEV and FCEV towards high mileage users (e.g., ensure that all taxi, private hire, and company car fleets are BEV/FCEV only by 2030)

[3] The UK has set the target to end the sale of petrol, diesel and hybrid cars and vans by 2030 and plug-in hybrid vans by 2035.

Bus and Coach	**Technology** – Very ambitious requiring strong financial support but a good investment given high number of zero-emission passenger km provided by a zero-emission bus in its life	End the sale of petrol, diesel, hybrid and plug-in hybrid buses and coaches by 2025. Start a repowering program so that by 2030 buses older than 15 years are scrapped or repowered with a zero-emission powertrain	Demand to increase as supply shifts from cars
Rail Passenger	**Technology** – Very ambitious requiring strong financial support but a good investment given high number of zero-emission passenger km provided by a zero-emission train in its life. **Behaviour** – Very ambitious change but possible if investment is focused on rail over roads and airports	Decarbonise the sector by 2035 in line with existing Scottish Government targets	Demand to increase as supply shifts from cars and domestic flights
Aviation	Very ambitious but fair given that all other sectors are delivering greater emission savings in the 2020s	A 33% reduction in emissions between 2019 and 2030 through continued incremental improvement through stock turnover, demand reduction and the introduction of Sustainable Aviation Fuels (SAF)	
Vans	**Technology** - Ambitious change but very achievable given the similar UK wide target. **Behaviour** – Ambitious change given the expected significant increase in van demand due to online shopping and the growth in trades needed in the decarbonisation transition (e.g., solar panel fitters, heat pump fitters, home insulation fitters, home charge point installers etc.)	End the sale of petrol, diesel, hybrid, and plug-in hybrid vans by 2030	Limit the growth in van demand to 10% between 2019 and 2030, reducing demand by 7% in 2030 compared to the BAU scenario

Trucks	**Technology** - Ambitious given that most debate in the UK focuses on a 2040 fossil fuel phase out target but achievable given how quickly the technology is progressing. The main barrier will be public infrastructure. **Behaviour** – Very ambitious requiring a complete overhaul of the supply chain, product standards and the interaction between completing businesses	End the sale of petrol, diesel, hybrid, and plug-in hybrid trucks by 2035. Allow existing policies to continue to drive the uptake of biomethane in the high annual mileage use cases. Ensure all truck are retrofitted with the latest aerodynamic and rolling resistance features by 2030	Shift 23% of all truck tonne.km onto rail or ships by 2030. Reduce truck tonne km by 15% by 2030 through a range of efficiency measures such as reducing food waste, improving product lifetime, optimising goods to vehicle allocation across and between fleets (backhauling, co-loading, physical internet)
Rail Freight	**Technology** – Very ambitious requiring strong financial support but a good investment given high number of zero-emission freight km provided by a zero-emission train in its life. **Behaviour** – Very ambitious change but possible if investment is focused on rail over roads and airports	Decarbonise the sector by 2035 in line with existing Scottish Government targets	Demand to increase as supply shifts from long haul truck routes
Shipping Freight	**Technology** – Very ambitious as technology is still at an early stage of development but possible given lessons learned developing zero-emission vehicles in other sectors. **Behaviour** – Politically very ambitious following other world leading countries by acting not just on fossil fuel use but also on production	**Domestic** - Large ZE vessels complete commercial demonstration by 2030 and start to enter the fleet in volume from 2030. Vessel powertrain retrofit programme starts in 2030 and ramps up to full capacity by 2035. **International** – Emissions drop by 50% by 2045 in-line with a slightly accelerated IMO target	**Domestic** – The transport of fossil fuels falls in-line with falling national demand. **International** – The export of fossil fuels to distant regions (e.g., Asia, America) stops very quickly and exports focus on Europe. By 2030 exports fall close to zero

2.2 Cars

2.2.1 Ambition

Cars are in the most advanced position in terms of decarbonisation potential with zero-emission tailpipe options available today and expected to accelerate quickly into the market with the UK Government's announcement to phase out petrol, diesel, and hybrid car sales by 2030. There are also multiple opportunities to reduce car kilometres through modal shift to public and active travel and demand reduction. For this reason, the car market has received the most attention and been given the largest emission reduction targets.

2.2.2 Technology

The major barriers to the widescale adoption of zero-emission cars are vehicle cost, availability of refuelling infrastructure and vehicle availability. The Total Cost of Ownership (TCO) of electric cars is coming down very quickly meaning that with policy support electric cars are now cheaper on a TCO basis than conventional cars in many markets in Europe. This means cost is quickly being addressed as a major barrier. Widening access to fast, reliable refuelling infrastructure is being addressed through schemes such as ChargePlace Scotland, and Scotland is in a position to accelerate the rollout of infrastructure to the level required to meet the emission targets. Vehicle availability is the greatest barrier for Scotland since no car manufacturers produce cars within Scotland, limiting Scotland's ability to influence zero-emission car production volumes.

Figure 6 shows projected European car production volumes by fuel type. It is projected that close to 2.5 million battery electric cars will be produced for the European market in 2025, equivalent to approximately 13% of total European car demand in 2025. It is expected that zero-emission car production will ramp up significantly post-2025, but with many countries setting increasingly stringent emission targets there will be a shortage of zero-emission car supply in Europe. This is particularly a problem in small markets such as Scotland, as these markets have lower purchasing power than larger European countries. This means it is unlikely that Scotland will be able to attract significantly more than its "fair share" of the zero-emission cars produced.

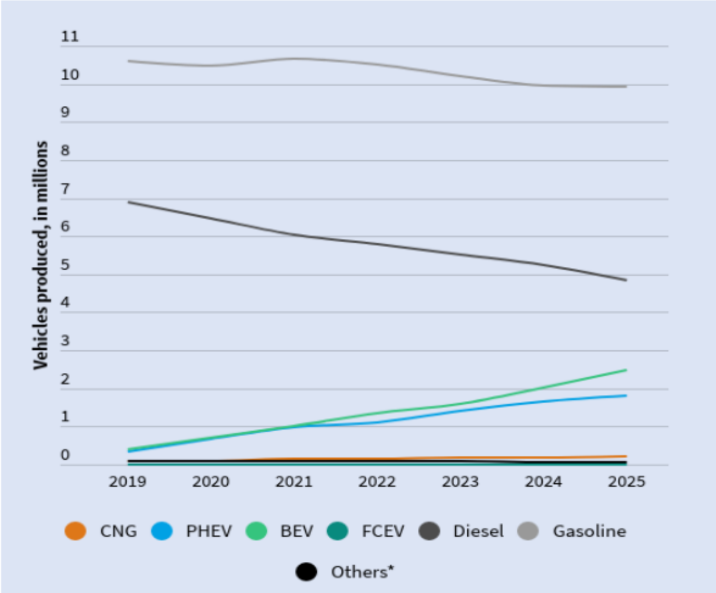

Figure 6: Projected vehicle production volumes in Europe by powertrain type. "Others" includes E100, E85, LPG (image taken from Transport & Environment, 2019, Electric Surge: Carmakers' electric car plans across Europe 2019-2025)

Given the UK commitment to **phase out petrol, diesel, and hybrid car sales by 2030** and PHEV car sales by 2035, Scotland can assume this level of ambition as a minimum. In this work we assume Scotland **adopts these targets but with the addition that PHEV are included in the 2030 phase out** because they will be more expensive than BEV on a TCO basis in 2030 and PHEV emission benefits relies on users regularly charging the vehicles, which has been shown not to be the case for many users of these vehicles today, making their emission benefits uncertain. Figure 7 shows the average new car tailpipe emission pathway proposed in this study and the impact this has on fleet tailpipe emissions in PS1, where no behavioural changes are assumed. It shows that ending the sale of fossil fuel powered cars in 2030 still leads to significant emissions from the car fleet throughout the 2030s.

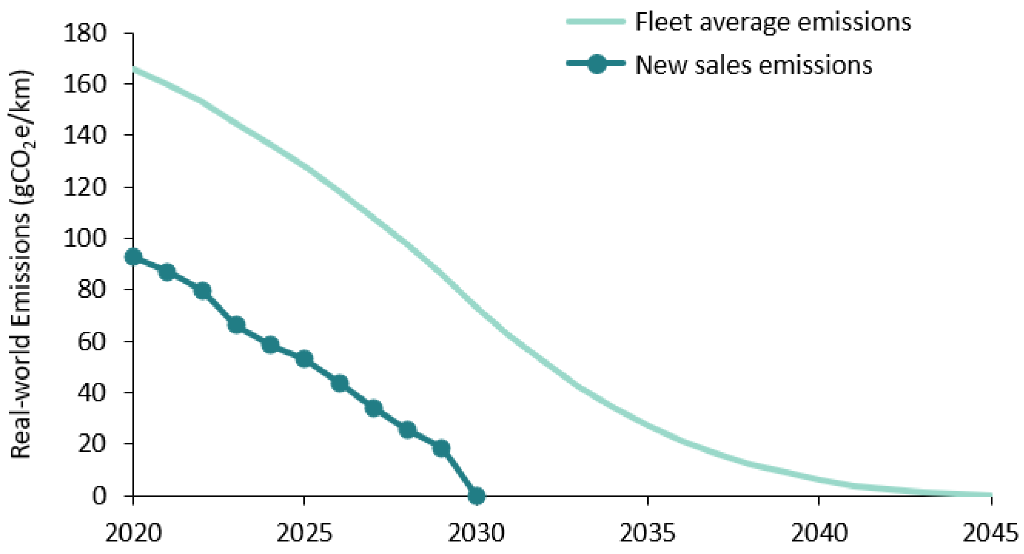

Figure 7: New car and fleet decarbonisation pathway in Policy Scenario 1, assuming all new cars are zero emissions from 2030.

The final technology policy outcome proposed for cars is a reduction in the number of larger cars, including SUVs sold. This change will see **the proportion of small cars increase from 40% of sales today to 60% of sales in 2030, with the increased achieved through a reduction in the sale of large salon and SUV cars**.

2.2.3 Behaviour

The Transport Model for Scotland expects the baseline demand for car travel to increase by 12% by 2030 and 27% by 2045 (see Transport Scotland, 2018, Transport Forecasts 2018) compared to 2019, due to population and economic growth. Six different behaviour changes have been studied to offset this growth in demand and reduce demand or eliminate emissions from high demand activities. These are:

1. **Trip Shortening** – The Scottish Government are currently considering supporting the rollout of 20-minute neighbourhoods in many areas of Scotland. These schemes aim to bring housing and services closer together helping to shorten trips and make more trips suitable for active travel. This change has no impact on the number of trips but reduces the length of each trip.
2. **Trip Avoidance** – A significant number of longer trips and very regular trips are work related, either to travel for meetings or commute to the office. Some of these trips could be replaced by teleconferencing and working from home, removing the need for the trip altogether.
3. **Modal Shift** – This means moving trips from high emissions per person modes such as cars and planes to low emission per person

modes such as walking, cycling, bus, and train. This change has no impact on the number of trips taken or the trip lengths.

4. **Vehicle Occupancy Rates** – The proportion of single occupancy car trips in Scotland has increased over time from 62% in 2007, to 64% in 2012 and up to 66% in 2017 (see Transport Scotland, 2019, National Transport Strategy). This trend matches a decline in overall car occupancy rates over time. Reversing this trend through ride sharing, either formal through apps or workplace schemes, or informally between neighbours is very important as it can have a significant impact with minimal additional infrastructure/cost requirements (these changes are assumed to increase car occupancy rate by 10% by 2030 in Scotland). This change has no impact on the number of trips taken or the trip lengths.
5. **Zero-Emission Vehicle/Trip Optimisation** – Zero-emission cars today are purchased by higher income households and are often popular for city/suburban users as traditionally the range of BEV has been short and air quality policy in cities adds additional impetus for the switch to zero-emission vehicles. These drivers do not encourage zero-emission car purchase/use by high mileage users, or for long distance trips, suggesting zero-emission vehicles actually offset less emissions than their numbers would suggest. However, many zero-emission vehicles are now entering the market with the range and refuelling technology to make them a viable option for long annual mileage users and for long trips. Encouraging zero-emission car sales into high mileage applications such as company car drivers, shared car fleets, taxi and private hire fleets etc. will mean each zero-emission car displaces more petrol/diesel car kilometres and therefore offsets more emissions. If delivered alongside the greater use of shared cars this trend could significantly reduce emissions in the 2020s.
6. **Shared Cars** – Although by itself not a driver of emission reductions, a shift towards shared cars in urban areas could support lower car ownership, more road space for public and active travel modes, better utilisation of zero-emission cars and higher occupancy rates.

These behaviour changes need to be encouraged, following a sustainable travel hierarchy, this means reducing demand first through trip avoidance and trip shorting then encouraging active travel, then public transport and finally more efficient use of cars. Overall major schemes to encourage modal shift in all urban and suburban areas, eliminating the use of private cars for short trips and trips into and around urban centres; alongside increased car occupancy rates, trip shortening, and trip avoidance can deliver a 20% reduction in car kilometres, relative to 2019. Given the need for behavioural change to support the most challenging target in 2030 these changes need to be delivered in the 2020s.

2.2.4 Emissions

Figure 8 summarises the decarbonisation pathway for cars. In this pathway close to 80% of the decarbonisation effort for cars is achieved by 2030 with only just over 20% left for the 2030s. This split of effort reflects the zero-emission technology maturity in the car market and the potential to increase the efficiency of private car mobility especially in urban and suburban areas.

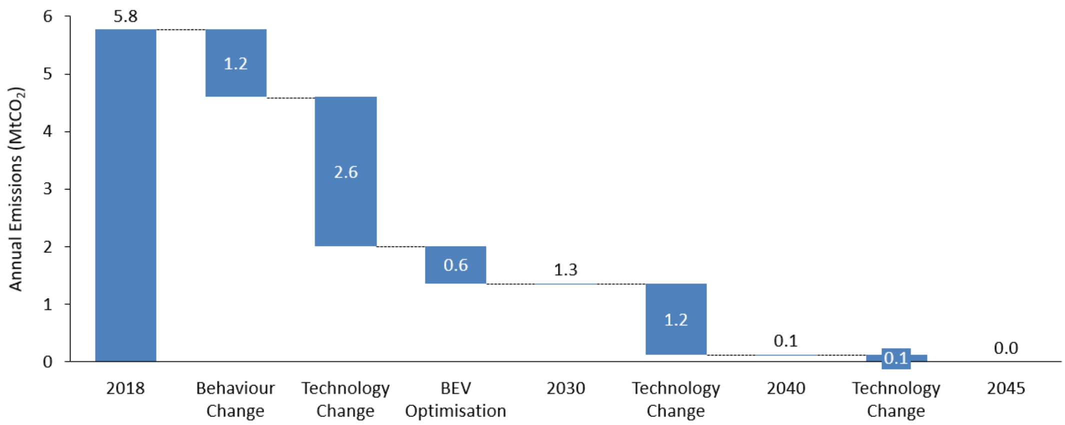

Figure 8: Car emission reduction due to technology and behaviour change in 2030, 2040 and 2045.

2.3 Buses and Coaches

2.3.1 Ambition

Buses and coaches provide a fundamental service offering flexible transport options in a space and emissions efficient manner. Bus and coach services have declined in Scotland, as well as in the rest of the UK, for several decades as the affordability and popularity of private cars has increased, directly resulting in increased emissions and congestion problems. Given that the bus and coach fleet is relatively small, meaning a direct economic intervention to clean the fleet is viable (the overall decarbonisation cost is small compared to the total cost of decarbonising the whole transport sector), buses and coaches can significantly reduce the emissions from the car fleet through modal shift, and Scotland has a zero-emission bus and coach OEM, reducing the constraint on vehicle supply, the bus and coach fleet should be an area where the emission targets are very ambitious.

2.3.2 Technology

The zero-emission bus market is relatively well developed in Europe with well over 5,000 zero-emission buses in operation, driven by air quality concerns in cities (see European Alternative Fuels Observatory, 2020, Buses). Scotland has been actively involved in this transition, with hydrogen buses deployed and planned in Aberdeen and Dundee and electric buses deployed in Glasgow, Edinburgh, and Inverness. By contrast, the zero-emission coach market is underdeveloped with battery electric and fuel cell models in development and going through early commercial testing by Original Equipment Manufacturers (OEMs), but with very limited options to purchase a zero-emission coach today (the first and only zero-emission coach in Scotland is run by Ember between Edinburgh and Dundee).

As with cars, the main barriers to the introduction of zero-emission buses and coaches are cost, refuelling infrastructure, and supply of vehicles. Coaches especially also face the challenge of meeting the range requirements of long-distance motorway travel with current zero-emission powertrain technology. The Scottish Government can directly impact the vehicle cost and the rollout of refuelling infrastructure through grants and loans. This means vehicle supply remains the main barrier to the rapid rollout of zero-emission buses and especially coaches.

An additional barrier to achieving deep decarbonisation of the bus and coach market is the long life of second-hand vehicles in small local fleets, which keep higher polluting vehicles on the road for a long time. For example, new buses are purchased by the big bus operators who can afford the significant investment (£150,000-200,000). After 10-15 years of service these buses are bought by smaller bus operators who keep them running until the maintenance costs become too high. Buses on the second-hand market can be purchased for as little £25,000 and can be kept running until the bus is 20-25 years old.

The supply of zero-emission buses in Scotland is improved by national production capacity provided by Alexander Dennis Ltd. (ADL), a bus body builder with headquarters in Larbert and production in Falkirk, offering both electric and hydrogen bus models. The Scottish Government should continue to work with OEMs across Europe to introduce zero-emission buses into the Scottish market as quickly as possible, taking advantage of the more advanced position of zero-emission bus supply and domestic production in the bus sector that Scotland cannot rely on in other road vehicle sectors. ADL also produce coaches through the Paxton brand. The Scottish Government could look to support ADL in transitioning their zero-emission expertise from the ADL bus brand to the Paxton coach brand to further encourage the supply of zero-emission coaches for the Scottish market.

To meet its climate change targets Scotland should prioritise the decarbonisation of its bus and coach fleet, because an extensive zero-emission public transport network can help to decarbonise all passenger transport, including trips currently undertaken by cars, and Scotland has a chance to quickly ramp up the number of zero-emission buses in the fleet with good supply offered by OEMs in Scotland, England and more widely in Europe. It is, therefore, **proposed that Scotland ends the sale of fossil fuel powered buses and coaches from 2025**. This is a very ambitious target but is in-line with the direction of the UK bus industry (the members of the Confederation of Passenger Transport (CPT), which represents most bus operators in the UK, have pledged to buy only Ultra Low Emission Buses (ULEB)[4] from 2025 if government puts in place the right support to overcome purchase price and infrastructure barriers (see CPT, 2021, Written evidence submitted by the Confederation of Passenger Transport). Extending the CPT pledge to zero-emission buses should be possible government support focuses on zero-emission instead of ULEV buses).

To deliver the rapid decarbonisation of the whole bus fleet, Scotland should also support the repowering of older buses. In the UK, Magnetic Systems Technology (Magtec) and Vantage Power both offer solutions to repower buses (replace current powertrain) to electric powertrains. **By 2030, all buses manufactured prior to 2015 must have been scrapped or repowered if Scotland is to meet its 2030 targets**. Repowering can often be too expensive for small bus operators, but an alternative scheme where older buses are purchased by a third party, repowered, and then rented back to bus operators should be explored.

Figure 9 shows the average new bus/coach tailpipe emission pathway proposed in this study and the impact this has on fleet tailpipe emissions in PS1, where no behavioural changes are assumed. Between 2020 and 2030 buses manufactured before 2016 are repowered to electric drivetrains, which results in fleet average emissions being lower than new sales emissions.

[4] ULEB is defined as a bus with 30% lower well to wheel emissions than a comparable Euro VI diesel bus.

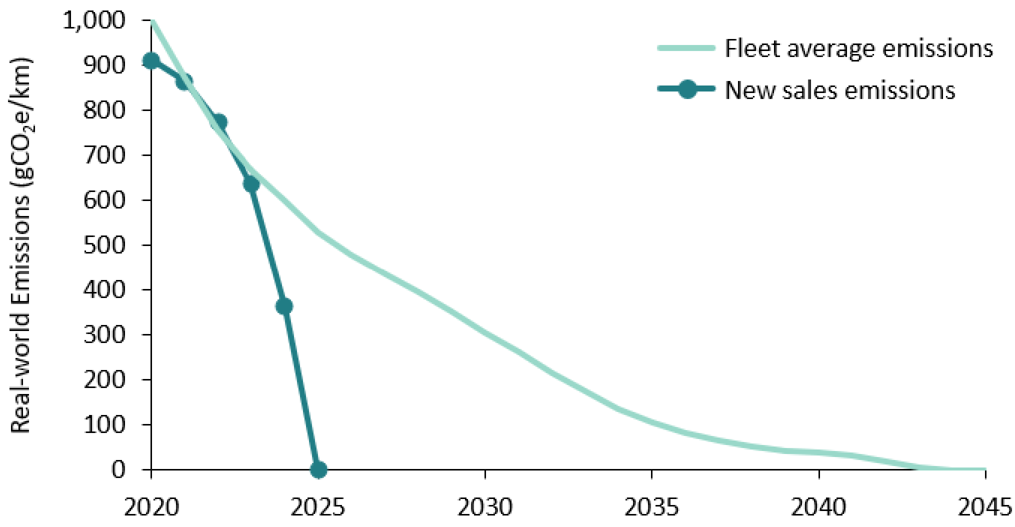

Figure 9: New bus and coach and fleet decarbonisation pathway in Policy Scenario 1, assuming all new buses and coaches are zero-emission from 2025.

2.3.3 Behaviour

The Transport Model for Scotland expects demand for bus and coach travel to fall by approximately 2% between 2019 and 2030 and by 5% in 2045 (see Transport Scotland, 2018, Transport Forecasts 2018). This follows a continuing decline over the last 10 to 20 years.

PS3 shifts car trips to buses and coaches by 2030 if the trip starts and ends within an urban area, in the urban/sub-urban band across Scotland[5] and the trip is between 1 and 30km in length. To reflect the increased bus demand in PS3, we have assumed that fleet average occupancy rates triple from 4.17 to 12.0 people per bus by 2030 (for comparison, the average bus occupancy in London is 19.3 (see DfT, 2012, Annual Bus Statistics: Great Britain 2011/12).

2.3.4 Emissions

As with the car market the emission reductions from buses and coaches are mostly achieved in the 2020s with an 80% reduction in emissions by 2030, at the same time as the demand for buses is growing. Achieving these changes will be very challenging, however, this is a sector where government financial support and regulation is well spent as a zero-emission bus fleet offers many emission, congestion, and health benefits.

[5] Edinburgh, Glasgow, Aberdeen, Dundee, Renfrewshire, West Dunbartonshire, East Dunbartonshire, East Renfrewshire, North Lanarkshire, Falkirk, West Lothian, Inverclyde

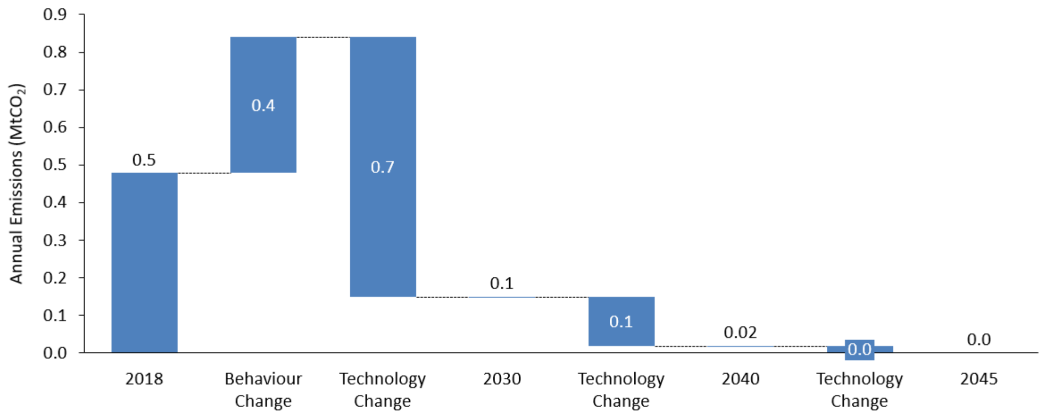

Figure 10: Bus and coach emission reduction due to technology and behaviour change in 2030, 2040 and 2045.

2.4 Rail Passenger

2.4.1 Ambition

The ambition in the rail sector has already been set by the Scottish Government's commitment to decarbonise rail transport by 2035. This puts rail at a very similar level of ambition to buses and cars with most of the decarbonisation effort required in the next 10 years.

2.4.2 Technology

Electrification of railways is a tried and tested method for decreasing rail emissions; however, the significant upfront cost of line electrification limits the routes on which this solution can be cost effective. Transport Scotland figures show that in 2018/19, 56.6% of passenger train vehicle km were under electric traction, an increase on previous years due to completion of the Edinburgh Glasgow Improvement Programme. This study uses projections for the uptake of overhead electrification and alternative fuel technologies provided by Transport Scotland, which showed that a maximum 82% of passenger train vehicle km will be under electric traction in 2045. Assuming that the maximum pathway for electrification outlined by Transport Scotland is achieved still requires that the rest of the network is decarbonised through the introduction of battery and hydrogen powered trains.

Although there are currently no trains operating in the UK with these technologies, several rolling stock manufacturers are developing battery and hydrogen passenger trains for possible introduction in the next few years. For shorter routes and routes with incomplete overhead electrification, battery and battery-electric hybrid trains are ideal replacements to diesel drivetrains. Transport for Wales has ordered several tri-mode diesel-electric-battery hybrid units from Stadler Rail, as well as five diesel-battery hybrid units from Vivarail, all of which are to be delivered by 2023. With the support of Transport Scotland, Vivarail trialled their battery-operated Class 230 on the Bo'ness and Kinneil Railway in October 2018, and they currently produce the only battery-only train available to the UK market (see Vivarail, 2019).

For longer distance routes, hydrogen fuel cell trains will likely be required. Although hydrogen trains currently operate in Germany, the smaller loading gauge of the British Rail network compared to that of mainland Europe results in additional technical challenges to hydrogen train technology in the UK. To date only Alstom, in collaboration with the rolling stock company Eversholt Rail, has announced a hydrogen train built for the UK network, their converted Class 321 'Breeze' trains, which are projected to run from 2022.

Transport Scotland is working with Network Rail to progress electrification projects (benefiting freight and passenger services), and explore where it is appropriate to operate battery and hydrogen fuel cell powered fleets to allow early replacement of diesel trains, at the same time discussions with rolling stock manufacturers are on-going around specifications. The Zero Emission Train (ZET) project is currently making good progress and will fully test hydrogen powered traction options, which will be required where electrification is not appropriate, across rural areas such as north/west of Inverness, west Highlands and Ayr-Stranraer lines. This will address the issues associated with creating, approving and then enabling, a hydrogen-fuelled train to operate at Bo'ness later this year.

The Transport Model for Scotland expects demand for train travel to increase by approximately 17% between 2019 and 2030 and by 40% in 2045 (see Transport Scotland, 2018, Transport Forecasts 2018). In PS3 car trips are shifted to trains by 2030 if the trip starts and ends within an urban area, in the urban/sub-urban band across Scotland[5] and the trip is longer than 30km.

2.4.3 Emissions

With the Scottish Government's target of decarbonising rail by 2035 the rail sector must demonstrate high ambition in the 2030s reducing emission by 65% by 2030 while also allowing significant growth in demand caused by modal shift from cars (see Figure 11) and aviation (see Figure 12).

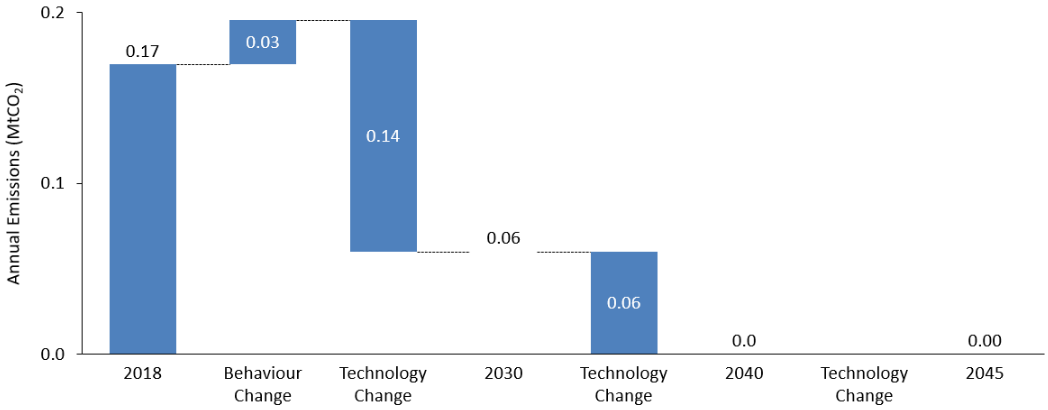

Figure 11: Passenger rail emission reduction due to technology and behaviour change in 2030, 2040 and 2045 (with model shift from cars)

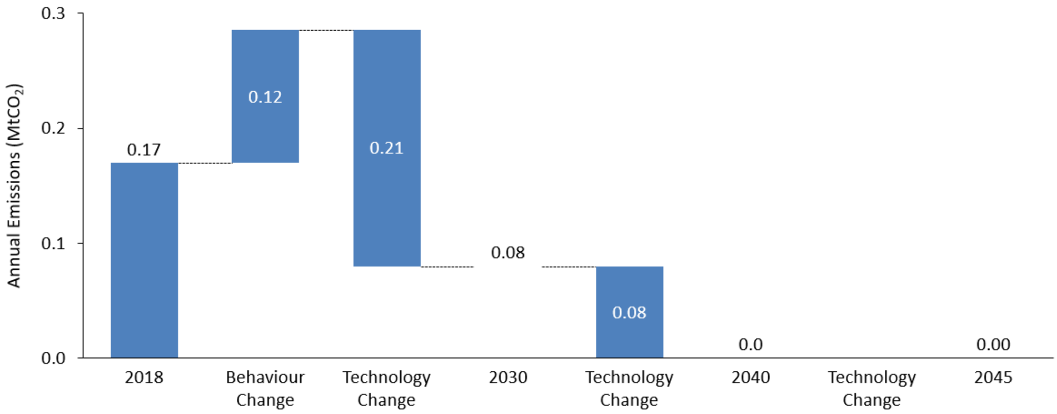

Figure 12: Passenger rail emission reduction due to technology and behaviour change in 2030, 2040 and 2045 (with model shift from cars and aviation)

2.5 Aviation

2.5.1 Ambition

Compared to other sectors the progress in the aviation sector to develop low/zero emissions vehicles has been limited, and remains at a very early stage. The limited progress in the aviation sector has been partially due to the challenging technical nature of decarbonising aviation, and the lack of policy intervention that has resulted as a consequence of the international nature of the aviation industry, which requires international cooperation in order to limit emissions leakage. However, given that aviation emissions are so heavy skewed towards a small number of high-income frequent flyers (DfT survey data from 2018 shows 48% of people surveyed did not take a single international flight in a year, while just 1% of the population took just less than 20% of all international flight in a year (see The

Guardian, 2019), it is clear that under a just and equitable decarbonisation transition the ambition in the aviation sector needs to increase significantly. This step change in ambition is needed in order for the cost of decarbonisation to be shared fairly, rather than sectors such as cars, vans, and public transport, where cost rises disproportionate impact low-income groups, having to make up for emissions not reduced in the aviation sector, where cost increases are focused on higher income groups.

2.5.2 Technology

Aviation is an incredibly challenging sector to decarbonise, as there are currently no known zero-emission fuels or energy storage technologies that can achieve the energy densities required for aviation at the price or production levels necessary to sustain a viable business.

In line with the Committee on Climate Change (CCC), we have based our assumptions on the decarbonisation of the aviation sector analysis undertaken for the CCC and DfT by Air Transportation Analytics Ltd and Ellondee Ltd (see Air Transportation Analytics Ltd and Ellondee Ltd, 2018), which looks at the projected availability of new aircraft technologies and the fuel and emissions savings that each new technology contributes. Given that decarbonisation of aviation is highly reliant on the emergence of new and untested technologies, almost entirely out of the control of the Scottish Government, we have taken the report's 'likely, nominal' scenario in all cases.

The short and long-haul aviation markets are dominated by two main aircraft manufacturers; Airbus and Boeing, both of which have recently released new product lines. Given that new aircraft are introduced roughly every 15 years, we would expect new technologies to start entering the aviation market sometime in the mid-2030s, with a second-generation entering service after 2045. As such, we do not expect to see any electric or electric-hybrid propulsion aircraft enter service until after 2045, which is in line with the findings of the CCC-commissioned study.

In order to meet Scotland's 2045 net-zero target, we have assumed the rollout of sustainable aviation fuels. It is expected that these will initially be based on biofuels as this technology is understood today and offers opportunities for significant scale up in the short to medium term. In the longer term it is expected that all biomass used for energy will need to be processed into electricity or hydrogen in a production plant with CCS to help offset remaining economy wide emissions. This means sustainable aviation fuels will need to transition to production via Power to Liquid (PtL) with early blending occurring from 2030 and ramping up to reach high blend levels by the 2040s. However, it should be noted that Scotland has very limited policy control over the amount of SAF blended into flights that arrive and leave Scottish airports to the rest of the UK and the rest of the world. SAF adoption is therefore only a viable solution if Scotland can work with other countries to agree policies that drive up SAF adoption across large regions and eventually globally.

This study has found that in order to meet its emission targets domestic and international aviation emissions assign to Scotland need to fall by 33% between 2019 and 2030, this is against a baseline scenario with expected significant growth in demand. If this full emission reduction where to be achieved by biofuel based SAF, Scotland would need to achieve a SAF blending rate of over 50% by 2030. Given the very early stage of commercial rollout of SAF and Scotland's limited control of fuel supply, achieving this would be very challenging. A more realistic scenario could see SAF blending at 10-20% by 2030 which would need to be paired with some behavioural change in order to meet the overall emission reduction target.

It should also be noted that the report used by the CCC and which underpins our assumptions in this study does not consider aircraft with fewer than 70 seats. It is expected that fully electric planes of this size class will be available due to their reduced weight and lower range requirements, and Scotland is already accelerating this market through projects such as the SATE projects which will test small zero-emission planes in Scotland over the next 18 months (see HIAL, 2021, HIAL leads £3.7 million sustainable aviation project at Kirkwall Airport). These planes have not been modelled in detail in this work because smaller planes operating short internal routes in Scotland represent a very small proportion of total aviation emissions and demand.

2.5.3 Behaviour

Demand for domestic and international aviation is not included in the Transport Model for Scotland. We, therefore, follow UK projections (Data on main Scottish airports taken from: UK Department for Transport, 2017, UK Aviation Forecasts) which expect aviation demand to increase by 14% between 2019 and 2030 increasing to 41% in 2045.

Given the very significant challenge of scaling up SAF volumes to deliver high blending rates by 2030 (due to low volumes of production today and the high-cost premium over fossil kerosene) some combination of SAF blending and behavioural change is expected to be the lowest risk pathway to meeting Scotland emission targets. If SAF uptake does not significantly increase in the next 10 years, then meeting the emissions targets would mean reducing domestic and international plane km by 33% between 2019 and 2030. With some SAF uptake, such as 15%, this demand reduction could be reduced to a 24% reduction in plane km between 2019 and 2030. As set out in the introduction carbon offsetting and trading are modelled outside of the emission envelope used in this study and therefore cannot contribute to the 33% emission reduction target.

2.5.4 Emissions

Aviation emissions have been rising rapidly as demand significantly outstrips efficiency improvements. For the aviation sector to be on track to meet Scotland's 2030 emission target this trend must be reversed and the sector must achieve a 33% reduction in emissions over the next ten years. Given the significant change over a relative short period this will likely require a combination of technology and behavioural changes. The aviation sector may achieve greater emission saving than this through schemes such as CORSIA which rely on offsetting. However, the emission envelope for transport in Scotland, used as the emission targets in this study for 2030, 2040 and 2045, are produced using the TIMES model which provides the targets after analysing the opportunities for offsetting. Offsetting schemes are therefore outside the scope of this analysis as any offsetting used here would be double counting offsetting capacity already accounted for in the TIMES model.

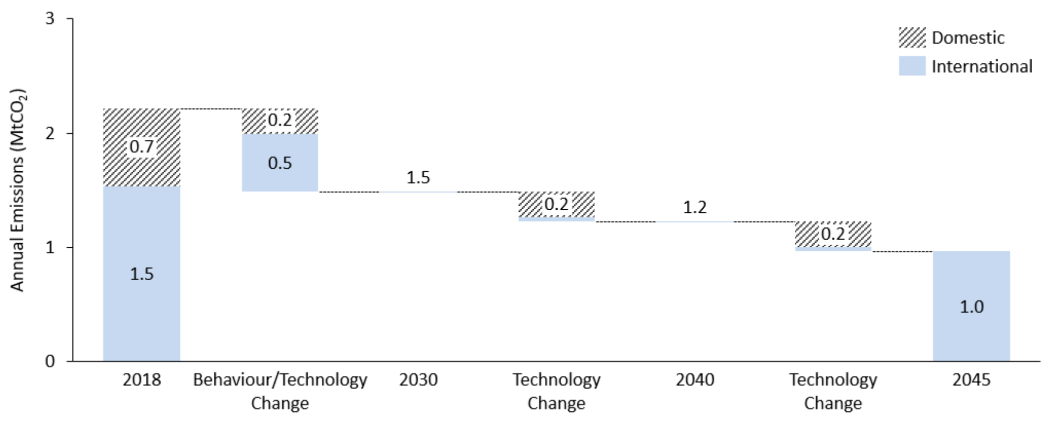

Figure 13: Aviation emission reduction due to technology and behaviour change in 2030, 2040 and 2045.

2.6 Vans

2.6.1 Ambition

By matching the date for petrol, diesel, and hybrid van sales phase out to that of cars significantly increases the ambition in the van sector and helps to being vans in line with the ambition across transport. However, the limited opportunities for modal shift and efficiency improvement in van operations and the rapid growth of this sector means vans remain one of the higher emitting sectors into the 2030s.

2.6.2 Technology

The zero-emission van sector is significantly behind the car market with only a fraction of the number of zero-emission models available. However, many van OEMs are also car OEMs meaning learnings and technology developed for the car market could be quickly transferred to the van market to grow the sector. Zero-emission vans will also benefit from the refuelling infrastructure installed to support the zero-emission car market. Due to this the UK has also committed to **phase out petrol, diesel, and hybrid van sales by 2030** and PHEV van sales by 2035. Again, we suggest Scotland takes this as a starting point, but goes further by **including PHEV in the 2030 phase out**.

Figure 14 shows the average new van tailpipe emission pathway proposed in this study and the impact that this has on fleet tailpipe emissions in PS1, where no behavioural changes are assumed.

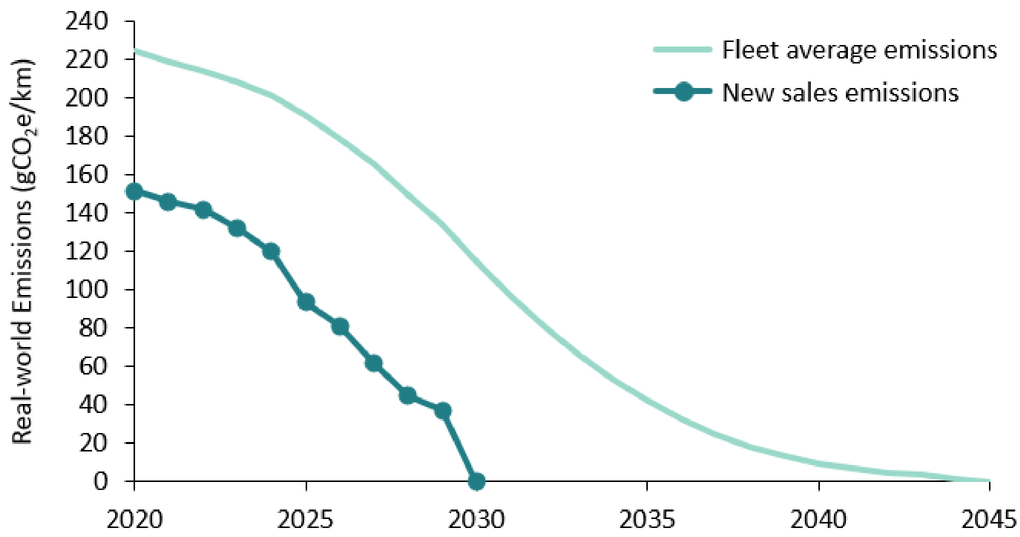

Figure 14: New van and fleet decarbonisation pathway in Policy Scenario 1, assuming all new vans are zero-emission from 2030.

2.6.3 Behaviour

The Transport Model for Scotland expects demand for goods vehicles to increase by approximately 20% between 2019 and 2030, and 50% between today and 2045 (see Transport Scotland, 2018, Transport Forecasts 2018). The majority of this growth is driven by vans, which DfT predicts will increase by 18% and 43% by 2030 and 2045 respectively (see Department for Transport, 2018, Road Traffic Forecasts 2018).

Figure 15 shows DfT survey data on van demand by sector for 2008 and 2020. The figure shows that while the van market has grown between 2008 and 2020 the proportions of van use have not changed significantly. Given that demand reduction though efficiency improvements only impact the collection and delivery of goods, there is limited opportunity for large fleet wide levels of behavioural change. In the 6th Carbon Budget, the CCC has targeted a 3% reduction in van mileage, compared to the baseline projections in 2035 (see [CCC, 2020, The Sixth carbon Budget - The UK's Path to Net Zero]). This level of ambition is not in line with the ambition set out for other sectors or with meeting Scotland's emission targets. Scotland should therefore target to limit van demand growth to 10% between today and 2030 instead of the projected 18% growth. This is equivalent to a 7% reduction in van mileage, compared to the baseline projections in 2030.

Zero-emission vans are currently used in very short-range applications owing to their short range. However, this is expected to change quickly as long-range vehicles and better refuelling infrastructure arrive. This means that like cars there is some potential to reduce emissions by encouraging zero-emission van uptake in high mileage motorway applications rather than low mileage city applications.

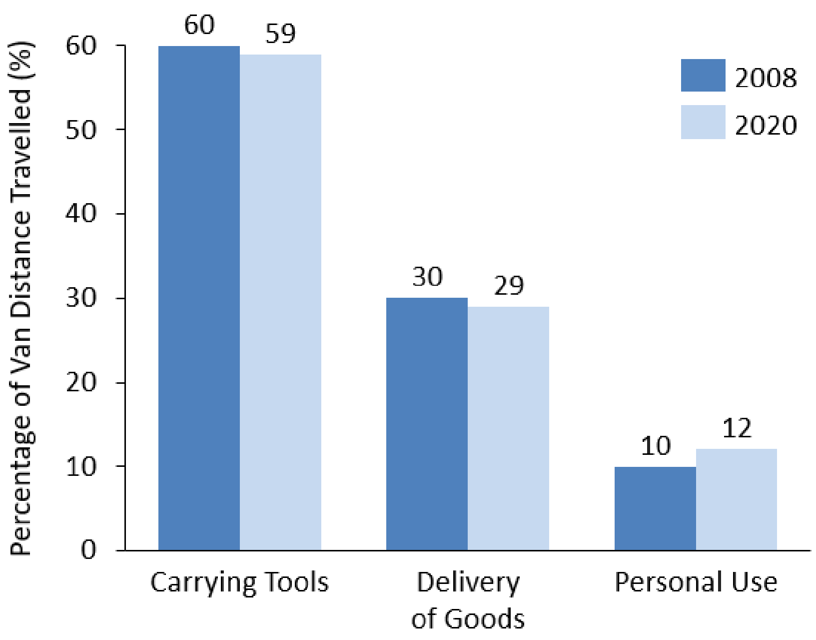

Figure 15: Van distance travelled by vehicle usage type for 2008 and 2020 (van users with no stated sector in the DfT survey have been assigned to each sector in the proportion given by other respondents see DfT, 2020, Van Statistics).

2.6.4 Emissions

Figure 16 shows the emission pathway for vans. Overall emissions are reduced by close to 50% by 2030. This is achieved primarily via the introduction of zero-emission vans, but the optimisation of zero-emission vans in higher mileage applications still plays a significant role, even though the assumed maximum potential for this strategy is constrained compared to cars due to the lower maturity of the market today.

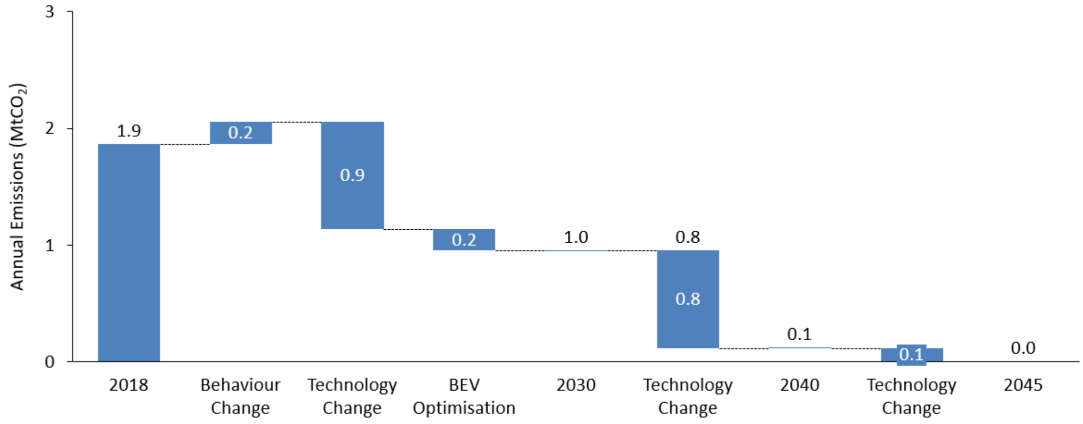

Figure 16: Van emission reduction due to technology and behaviour change in 2030, 2040 and 2045.

2.7 Trucks

2.7.1 Ambition

Zero-emission technologies in the truck sector are at a relatively early stage of development making it very challenging to deliver significant emission reductions through this route. However, this sector can still show significant ambition by adopting bridging technologies such as biomethane for high mileage trucks, shifting focus away from trucks to rail and coastal shipping for the movements of goods from southern England, and through a step change in truck freight operator behaviour with complete integration of technologies designed to optimise freight movements within single operators but also across companies and modes.

2.7.2 Technology

The zero-emission truck market is at a very early stage of development with a number of OEMs currently conducting early customer trials of pre-commercial vehicles. The larger size, longer daily mileages and shorter stop periods of trucks all add additional challenges to the adoption of zero-emission vehicles. The main barriers to the introduction of zero-emission trucks are technology readiness, vehicle cost, refuelling infrastructure, and vehicle availability.

Zero-emission powertrains are being developed predominantly for rigid trucks conducting urban or inter-urban operations (average 250-300km driving per day). These vehicles have a large space under the truck bed to store batteries or hydrogen and do not travel very long distances each day meaning that the daily profile can often be met with current zero-emission powertrain technologies. However, total truck emissions are skewed towards articulated trucks operating long daily distance along motorway and rural routes (average 350-450km a day but can do up to 800km a day). Further zero-emission powertrain technology development is needed before a commercial vehicle can be offered in this more challenging sector and this is reflected in our assumption that the complete decarbonisation of new truck occurs later than for other road vehicles. Bringing long haul zero-emission trucks to market will take time and technology development and user confidence could be supported by large scale commercial demonstrations (this process has already begun with the UK Government committing to "We will invest £20 million next year in freight trials to pioneer hydrogen and other zero emission lorries, to support industry to develop cost-effective, zero-emission HGVs in the UK" as part of the 10 Point Plan - see UK Government, 2020, The 10 Point Plan for a Green Industrial Revolution), especially for challenging routes to reach rural communities.

The large weight of trucks and the long daily distances covered mean that trucks consume a very large amount of energy each day. Packaging this amount of energy, in the form of batteries or hydrogen, on the vehicle is very challenging and results in very high capital cost for these vehicles. The large amount of energy used by trucks and the demanding daily schedules also makes refuelling these vehicles more challenging. The high refuelling rates needed by trucks are currently not covered by refuelling standards for electricity or hydrogen. This will need to be addressed before investment in medium or long range zero-emission trucks can gain pace.

Overcoming all of these challenges to encourage the supply of zero-emission trucks into the market is outside of Scotland's influence. Even with significant policy support to overcome the capital cost differential, there are unlikely to be a meaningful number of zero-emission trucks in the Scottish market before the mid-2030s. To help overcome this, Scottish fleets, with the coordination support of the Scottish Government, could agree a small number of zero-emission truck specifications that meet the needs of a significant number of truck applications in Scotland and then actively seek a truck manufacturer willing to offer a truck that meets the specification. This process of actively seeking zero-emission truck supply by offering a single OEM a large zero-emission truck order can help to overcome many issues simultaneously. Most importantly it ensures the supply of vehicles that meet Scottish truck operators needs and can help to bring down prices if the order is of sufficient size.

This process of actively drawing supply into the market has been successfully demonstrated in Switzerland and New Zealand. In Switzerland, a tax on trucks was introduced to encourage a shift from road to rail freight. This tax is based on the size and mileage of the truck and is set very high, costing the average small truck £20,000 per year and the average large truck £50,000 a year. When this tax was wavered for zero-emission trucks, a collaboration of truck operators and fuel suppliers agreed a truck specification and approached truck manufacturers around the world to find one willing to develop a truck to meet the specification for the guarantee of significant demand for the truck. Hyundai agreed to meet the truck specification and has formed a joint venture with Switzerland-based H2Energy, who coordinated the search for a truck manufacturer, to deliver hydrogen trucks and associated refuelling infrastructure in Switzerland. The joint venture has agreed to deliver hydrogen trucks to the Swiss market on a per km charge basis meaning that the truck operators do not need to pay high upfront capital costs and are guaranteed truck maintenance and fuel supply. This offer has proved very successful in Switzerland and the number of trucks in the order has increased several times and now stands at 1,600 hydrogen trucks to be delivered between 2020-2025.

As the supply of zero-emission trucks before 2030 is expected to seriously limit the uptake within Scotland, **it is proposed that Scotland attempts to recreate the demand driven approach achieved in Switzerland**. In this modelling it is assumed that two truck procurement exercises occur, one running from now to 2025 and a second running from 2025 to 2030. The first procurement exercise matches the scale of the Swiss project ordering 1,600 zero-emission trucks to be delivered by 2025. The second procurement exercise increases in ambition, ordering 6,400 zero-emission trucks to be delivered between 2025 and 2030. After 2030 it is expected that zero-emission truck supply chains will be mature enough that truck operators will be able to order zero-emission trucks through current suppliers. Given the zero-emission truck supply chains that Scotland will have developed by 2030, **Scotland should be in a position to end the sale of fossil fuel powered trucks by 2035**.

Figure 17 shows the average new truck tailpipe emission pathway proposed in this study and the impact this has on fleet tailpipe emissions in PS1, where no behavioural changes are assumed. The pathway in the figure captures the impact of the EU truck efficiency standards[6] and the proposed zero-emission truck procurement scheme discussed earlier in

[6] EU truck CO_2 targets, introduced in 2019, set a target to reduce haulage truck CO_2 emissions by 15% and 30% by 2025 and 2030 respectively, relative to 2019.

this section. Decarbonising new trucks by 2035 is an incredibly ambitious target given the current state of the market.

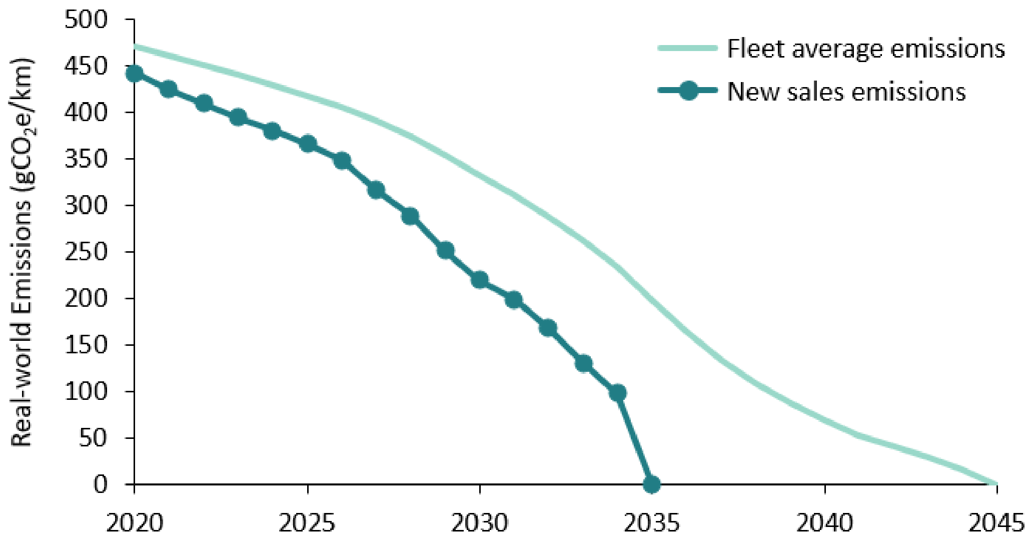

Figure 17: New truck and fleet decarbonisation pathway in Policy Scenario 1, assuming all new trucks are zero-emission from 2035.

While zero-emission vehicles are very important for decarbonising the HGV sector, the low technology readiness means it is not in a good position to deliver significant fleet wide emission benefits by 2030. Across the UK there is now growing interest in the use of biomethane as a fuel for high mileage trucks. Supported by the RTFO and the gas fuel excise duty rebate, running high mileage trucks on biomethane is cost effective for truck operators today and offers on average an 85% (see LowCVP, 2020, Low Emission Freight Trials) reduction in well to wheel emissions compared to diesel, in 2019 80% of the CNG and LNG dispensed to trucks in the UK was biomethane. As long as policy makers ensure CNG and LNG remain mostly biomethane, and not natural gas, as the industry expands, and feedstocks remain wastes and residues and not food crops (expected to be the case as the RTFO rewards for waste and residue-based fuels is double making a better business case) then small (most biomethane is assumed to be used to decarbonise heat) amounts of biomethane in transport can support overall decarbonisation. The main limiting factor to biomethanes potential to decarbonise heat and transport in the 2020s and 2030s is supply and so **it is essential that policy is effective at ensuring most biomethane feedstocks available in Scotland are utilised by 2030**.

It is also possible to retrofit existing trucks with technologies that improve aerodynamics and reduce rolling resistance, reducing fuel consumption and emissions. **We have assumed that existing technologies can**

provide an 8% increase in fuel efficiency and that by 2030 the entire truck fleet is retrofitted with these technologies (see IEA).

2.7.3 Behaviour

The Transport Model for Scotland expects demand for goods vehicles to increase by approximately 20% between 2019 and 2030, and 50% between today and 2045 (see Transport Scotland, 2018, Transport Forecasts 2018). Only a small proportion of this growth is expected to come from trucks, 1% and 6% by 2030 and 2045 respectively (see Department for Transport, 2018, Road Traffic Forecasts 2018).

The main modal shift option captured in PS3 for trucks is to rail. This delivers significant benefits, even with today's diesel freight trains, with one freight train replacing up to 76 trucks and reducing the emission per tonne km by an estimated 76% to 90% (see Transport Scotland, Delivering the Goods Scotland's rail freight strategy and Alan McKinnon, CO2 Emissions from Freight Transport: An Analysis of UK Data). Another modal shift option is from trucks to ships, again this potentially offers significant carbon reductions as coastal shipping is expected to deliver an estimated 80% (see Alan McKinnon, CO2 Emissions from Freight Transport: An Analysis of UK Data) reduction in emissions per tonne km. The EU has a target for freight modal shift from road to rail (and waterways) of 30% by 2030 and 50% by 2050, for distances greater than 300 kilometers (see Transport Scotland, Delivering the Goods Scotland's rail freight strategy). **For Scotland to meet its emission targets this ambition needs to be increased to 23% of truck tonne.km must be shifted away from road freight** (this is expected to be predominantly on longer routes and is equivalent to all road freight moved over 400km, although exact routes shifted to rail will depend on infrastructure). As the majority of long-haul road freight lifted in Scotland travels to England this means ensuring the East and West coast mainlines have capacity (rail freight capacity is discussed in the next section) and that Scottish port have the infrastructure to accept cargo that is currently routed through ports in the south of England.

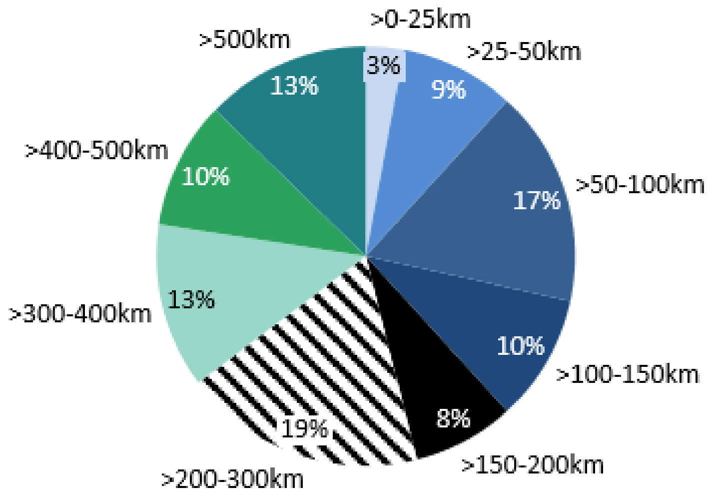

Figure 18: Goods lifted by HGVs in Scotland, with destinations within the UK (% tonne km – see Transport Scotland, 2018, Scottish Transport Statistics No. 37 2018 Edition Chapter 3: Road Freight)

PS3 also considers the potential to remove truck km travelled through reducing freight moved and improving freight system efficiencies.

Table 2 summarises changes truck operators could make to improve the efficiency of the truck freight system. Many of these changes relate to a similar system change and so the overall benefit of deploying all these changes is much smaller than the sum of their individual impact.

Table 2: HGV efficiency improvement options (see International Energy Agency, 2018, The future of trucks and UK Department for Transport, 2019, Domestic Road Freight Activity)

Action	Maximum Energy Saving Potential (%)
Remove all empty km	30% reduction in truck km
Operate trucks at maximum laden weight	37-69% reduction in truck km depending on truck size
Retrofit trucks with improved aerodynamic efficiency features	3-5%
Retrofit trucks with low rolling resistance tires	3-5%
Company level route optimisation	5-10% for intra-city and 1% for long haul
Shift to high-capacity vehicles	Up to 20%
Driver training and feedback	3-10%
Company level last mile delivery optimisation	5-10%
Supply chain collaboration / co-loading	Up to 15%
Matching cargo and vehicles via IT	5-10% in urban areas
Physical internet	Up to 20%

Truck demand can also be decreased by reducing the tonnes of goods moved. Figure 19 shows the split of goods moved by sector in Scotland. Activities, such as reducing food waste, avoiding the purchase of disposable or short life goods, and reducing packaging and waste, could all help to reducing truck km. Zero Waste Scotland estimated that 20% of all food purchased by Scottish households is wasted and that 60% of this waste is avoidable (Zero Waste Scotland, 2016, How much food and drink waste is there in Scotland?). Eliminating food waste will reduce the transport of food and agricultural products and by itself could lead to a 5% reduction in Scottish truck tonne km travelled.

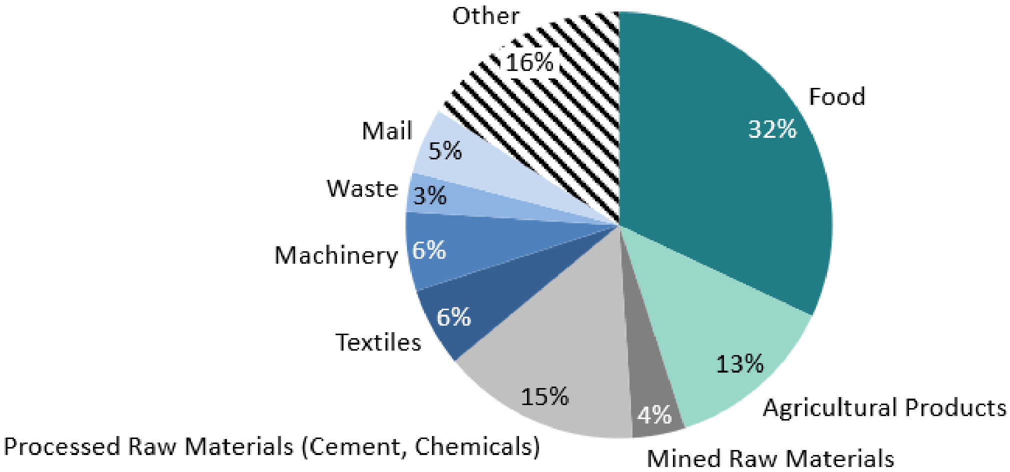

Figure 19: Scottish Goods moved by HGV by sector (% of goods moved in million tonne km – see Transport Scotland, 2018, Scottish Transport Statistics No. 37 2018 Edition Chapter 3: Road Freight)

Overall, it is estimated that demand for **truck freight tonne km could be reduced by 15% by a combination of operational efficiency improvements and demand reduction**. A key driver of this change is the introduction of the physical internet. The concept of the physical internet is that goods can be moved along the road network in the same way as packets of data move through the internet. Under this system goods are split into standardised packages of a set size that can be easily loaded and unloaded with similar goods or completely different goods at multiple points along the route. The packages are assigned to trucks in order to minimise trip distances, empty km travelled and trips where the truck is “full” either because it has reached its size or weight limit without hitting the trucks weight or size limit (e.g., a truck moving food could be full while not be at its weight limit or a truck moving steel could be at its weight limit while only being half full. Moving a combination of food and steel could allow the truck to meet its weight and size limit reducing the number of truck km required). Delivering the physical internet can help to reduce the 30% of truck km that are run empty and the 40% of the truck maximum weight carrying capacity which is not utilised (this could be helped by the introduction of high-capacity vehicles, which will require a change to truck size limits). However, delivering this goal will require collaboration between companies used to working as competitors, meaning a total cultural shift in the industry. To deliver this governments will need to sell a vision of the future where quality of service and price competitiveness are still rewarded while maximizing the efficiency of the whole system.

2.7.4 Emissions

Given the low state of zero-emission technology readiness in the truck sector, this sector has some of the most ambitious emission reduction targets with emission falling by 50% by 2030 due to significant changes in technology, transport modes and truck freight operator behaviour.

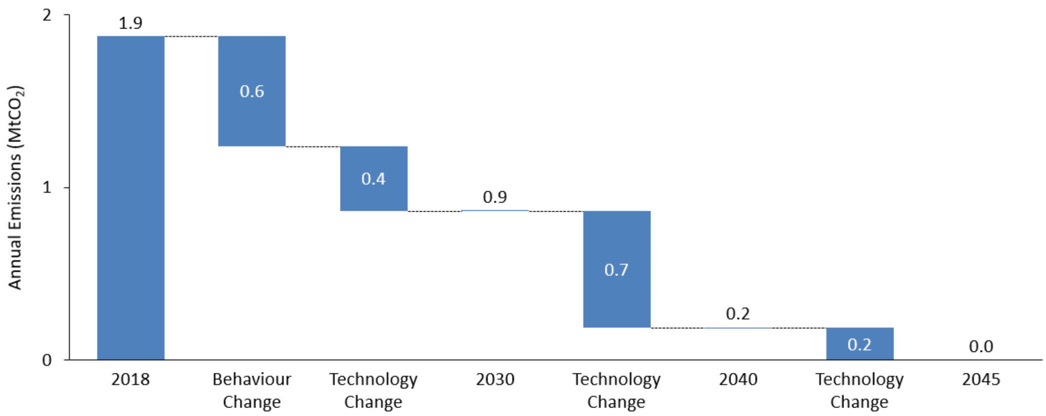

Figure 20: Truck emission reduction due to technology and behaviour change in 2030, 2040 and 2045.

2.8 Rail Freight

2.8.1 Ambition

The ambition in the rail sector has already been set by the Scottish Government's commitment to decarbonise rail transport by 2035. This puts rail at a very similar level of ambition to buses and cars with most of the decarbonisation effort required in the next 10 years.

2.8.2 Technology

The British rail freight fleet is dominated by diesel locomotives, and in 2016 only 5% of freight was pulled by electric locomotives across the GB network.

Despite many of the main freight corridors being electrified, freight locomotives currently need the flexibility to operate across the network and their routes often traverse non-electrified sections, meaning that diesel locomotives are used throughout and often travel 'under the wire'. The recently introduced British Rail Class 88 is an electric locomotive with last mile 'off the wire' capability thanks to an onboard diesel generator. Procurement of more heavy locomotives with this dual-fuel capability, in combination with a programme of electrification targeted at bottlenecks in the electrified freight network could significantly reduce the emissions from rail freight over the next ten years.

In the absence of a fully electrified network, heavy electric locomotives running on hydrogen fuel cells will need to be introduced to the network. Currently there are no such locomotives on the market, though with the UK Government's commitment to removing all diesel locomotives from service by 2040 we can expect to see these come onto the market over the next decade. In order to guarantee that there are no diesel locomotives operating within Scotland after 2035, Transport Scotland should work with the freight operating companies, rolling stock manufacturers, and Network Rail to ensure that hydrogen locomotives are made available to the GB market.

In many of the policy outcome scenarios modelled in this study, road freight is shifted to rail freight in order to reduce overall emissions. This intermodal freight will be focused on city-to-city rail traffic and therefore fall on the main electrified mainlines. To ensure that these new services are completed using electric traction, bi-mode locomotives should be procured to minimise diesel locomotives running 'under the wire', and line electrification should focus on sections of track currently limiting electric freight traffic.

Research by Transport Scotland indicates that Scottish rail freight, being predominantly moved along the major electrified corridors of the West and East coast mainlines, has a higher proportion of electric traction than the rest of GB, with 45% (see Transport Scotland, 2020, Rail Services Decarbonisation Action Plan) of rail freight in Scotland currently electrically hauled. In the modelling the 55% of diesel hauled rail freight decreases in line with passenger rail to zero in 2035.

2.8.3 Behaviour

Network Rail analysis of UK rail freight predicts that demand for rail freight, on a tonne km basis, will increase by 43% between 2015 and 2045 (Network Rail, 2019, Rail Freight Forecasts: Scenarios for 2033/34 & 2043/44). In PS3 additional freight is shifted from trucks to rail. The amount of freight that can be shifted to rail in the UK is dependent on the capacity of the rail network and the balance of capacity between passengers and freight with policies and investments needed to support an optimum balance on the shared rail network. Analysis of the rail network capacity suggests that reasonable actions can be taken to significantly increase the capacity of the East and West Coast Main lines by 2030 allowing Scotland to shift a significant proportion of the current road freight between Scotland and England over to rail (AECOM, ARUP, SNC Lavalin, 2016, Future Potential for Modal Shift in the UK Rail Freight Market).

2.8.4 Emissions

In this analysis the target for the rail freight sector is to keep emissions close to constant between today and 2030 while delivering significantly more tonnes of goods. It is beyond the scope of this analysis to provide a detailed breakdown of goods redistribution from trucks to rail and ships. Figure 21 therefore presents a scenario where all displaced truck movements are shifted to rail, as opportunities to upgrade Scottish ports for additional freight movements is not well understood, however in reality a mix of rail and shipping is expected to be optimal given the constraints on the rail network and the need to increase rail capacity for passengers and freight.

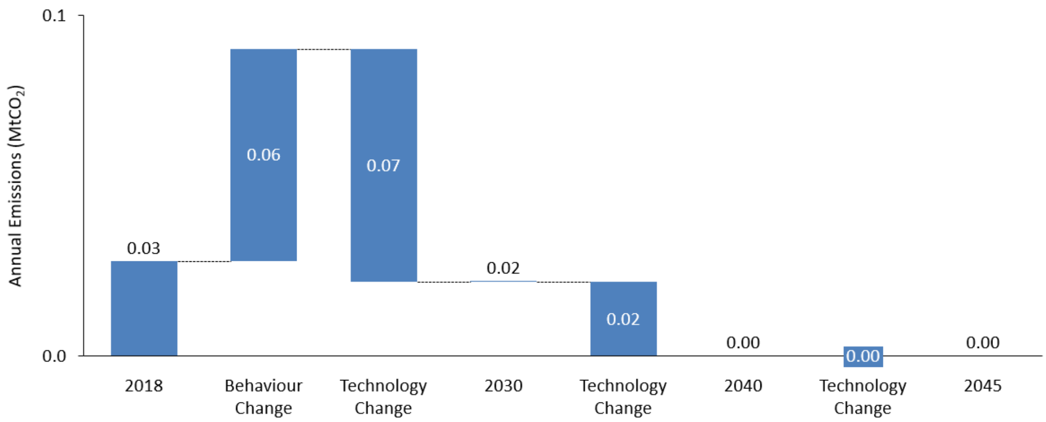

Figure 21: Rail freight emission reduction due to technology and behaviour change in 2030, 2040 and 2045.

2.9 Shipping Freight

2.9.1 Ambition

The shipping freight sector faces many of the same challenges as the aviation sector where fear of, economic loss, reduced competitiveness with other countries, and carbon leakage, if local policies are implemented, have limited progress, and with no ambitious international regulation the sector has been left with low zero-emission technology maturity. This has placed the sector in a poor position to respond rapidly to new decarbonisation policies and makes ambitious decarbonisation by 2030 very challenging.

However, like the aviation sector, the shipping sector also has an ethical problem that makes setting an ambitious trajectory vital for an equitable and just decarbonisation transition. In the case of shipping the ethical issue arises because a major proportion of Scottish domestic and international shipping emission arise due to the movement of fossil fuels. The movement of fossil fuels domestically cause less of a problem because the ambitious national targets to reduce emissions will drive down the demand and therefore transporting needs of these fuels. However, the export of these fuels internationally represents a case where the UK is still responsible for greenhouse gas emissions globally even if domestic emissions have been significantly reduced.

The production of fossil fuels in the North Sea is outside of Scottish Government control and sits with the UK Government. An ambitious strategy in this sector therefore requires that the Scottish Government is able to work with the UK Government to reduce emissions from the oil and gas sector and its associated transportation to close to zero. Like international aviation the freight shipping sector is an international market and strong commitments within Scotland, without any international efforts, could lead to a shift in trade to other regions. Scottish technology and behavioural change efforts will, therefore, not be as effective if they are not paired with highly ambitious international agreements, meaning the UK and Scottish Governments should put equal effort into technology development, behavioural change and international agreements to achieve carbon reductions in international transport sectors.

Given the low levels of technology readiness the strategy has to be very ambitious about the rollout of new and retrofit zero-emission vessel, **with capacity ramping up from 2030 and then delivering an overhaul of most of the fleet in the 10-year period between 2035 and 2045**.

2.9.2 Technology

Decarbonisation of the shipping industry is currently at a very early stage of development due to the challenges of regulating a global industry. Current analysis suggests that battery electric, hydrogen combustion, hydrogen fuel cells, ammonia combustion and ammonia fuel cells propulsion could all be viable fuels to help decarbonise certain sectors of the shipping industry (see Transport & Environment, 2018, Roadmap to decarbonising European shipping). Given that the key drivers of Scotland's shipping emissions are long-haul shipping of fossil fuels to the opposite side of the world and trawling fishing vessels, both of which consume very large quantities of fuel, it is assumed that liquid hydrogen or hydrogen derived ammonia will be central to the low emissions technology mix, alongside battery electric vessels for shorter routes.

The main driver of maritime decarbonisation is the International Maritime Organisation (IMO) target to reduce emissions from the sector by at least 50% by 2050. Analysis of pathways to meet this target suggests that zero-emission vessels need to start entering the fleet by 2030 with the supply quickly ramping up through the 2030s (see Lloyd's Register and UMAS, 2019, Zero-emission vessels: Transition Pathway). This analysis for transport Scotland assumes that Scotland will support the development of zero-emission ship powertrains and will be able to complete zero-emission ship trials by 2030. This will place **Scotland in a strong position to end the purchase/production of fossil fuel powered ships by the early 2030s and to build up a retrofit program to be running at full capacity by 2035**. By following this pathway Scotland should be able to completely decarbonise the domestic shipping fleet by 2045. However, it should be noted that a significant proportion of the international shipping fleet stopping at Scottish ports in 2045 will still be using fossil fuels.

2.9.3 Behaviour

Port freight cargo projections developed by the UK Department for Transport give the expected imports and exports of goods by type to UK ports out to 2050 (see Department for Transport, 2019, UK Port Freight Traffic: 2019 Forecasts). This analysis has been used to create Scottish-specific shipping freight projections based on the good types currently handled by Scottish ports. The baseline UK projections expect the overall tonnage of goods handled by UK ports to increase. However, the expectation is the tonnage of fossil fuels will fall and this will be displaced by other goods. As a disproportionately high percentage of Scottish shipping freight is fossil fuels our baseline projection for shipping demand sees a 20% reduction in shipping tonne.km between 2019 and 2045.

In PS3 the demand for domestic shipping is reduced further, relative to the baseline case, as a result of falling demand for fossil fuels for domestic transport, heating, and industry in the UK, which results in lower shipping transport requirements. In international shipping it is assumed that emissions from transporting fossil fuels are reduced close to zero by 2030. This could be through reduced fossil fuel exports and/or the reduced carbon intensity of transportation driven by Scotland accelerating the introduction of zero-emission ships far ahead of the pathway currently needed for the IMO target. **This results in a 40% reduction in domestic tonne km and up to a 96% reduction in international shipping tonne km relative to the business-as-usual case in 2045**.

2.9.4 Emissions

The emissions from domestic shipping falls at an accelerating rate over time, dropping by 20% in the 2020s, 50% in the 2030s and drops to zero in

2045. The early emission reductions are driven by reduced movements of fossil fuels for domestic consumption, later this is supported by the introduction of zero-emission powertrains, mostly through retrofit programmes, which ramps up and retrofits challenging fleets such as fishing vessels in the late 2030/early 2040s.

The emissions from international marine sector drop very close to zero in the 2020s from the single step of ending export of fossil fuels from Scotland to Asia which represents almost of all the tonne km of ships leaving Scottish ports for international travel.

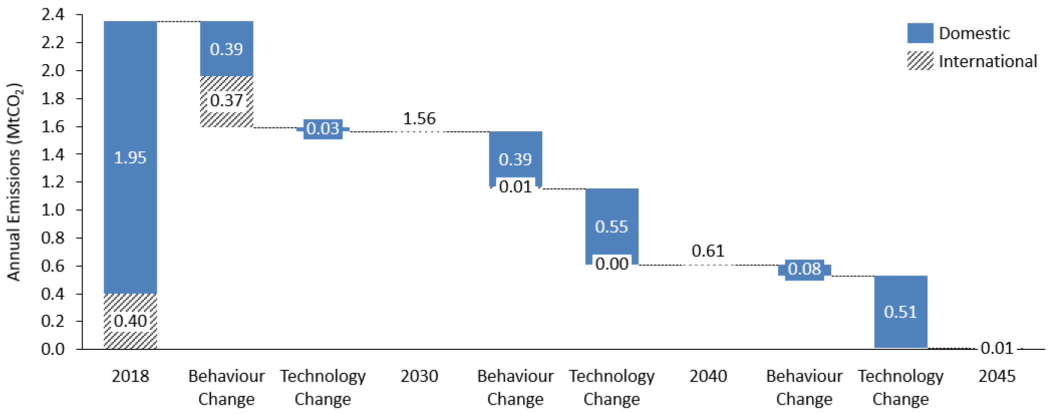

Figure 22: Marine emission reduction due to technology and behaviour change in 2030, 2040 and 2045.

2.10 PS3 Results and Discussion

PS3 is a very ambitious scenario requiring technology and behavioural change at a scale never before achieved in the transport sector. The main challenge for meeting Scotland's emission targets lies in delivering a policy package in the 2020s to drastically change how people and goods are transported. This is not something Transport Scotland can achieve alone as much of the policy needed falls under the jurisdiction of other government departments, Scottish local authorities, UK Government and international government agreements. There is, therefore, an inherent risk that this scenario cannot be achieved by the Scottish Government alone, pushing forward with ambitious decarbonisation plans, but requires other regions and nations to step up their ambition and support Scotland in this transition.

Once achieved the policy outcomes outlined in Table 1 provide significant emission reductions. The emissions per sector are summarised in Figure 23. It clearly shows that most of the emissions reduction efforts is required before 2030, with policy outcomes achieved by 2030, such as ending the sale of fossil fuel powered cars and vans, continuing to drive down emissions in the 2030s as the complete fleet transitions to zero-emission vehicles. Most of the emissions reduction by 2030 are achieved by the road transport sectors; however, by the 2030s non-road transport sectors are catching up and all transport modes contribute significant emission reductions by 2040.

Most of the policy effort for PS3 is required in the 2020s with the total shift in car and van sales to zero-emission vehicles, the market development and significant expansion of zero-emission truck market, the demonstration and early acceleration of low/zero-emission fuels in the marine and aviation sector, and all the major behavioural changes proposed, needed by 2030.

In the 2030s there will still be significant work required continuing to rollout zero-emission road vehicle infrastructure, ramping up SAF production and delivering a major marine engine retrofit scheme. This will require major changes for the sectors involved but will have much less of an impact on the general public compared to changes needed in the 2020s. Finally, in the 2040's most of the policy actions have already been completed and the final emissions are removed as existing schemes run to completion. Overall, there is no reason why any direct emissions should remain from the road transport sector in Scotland in 2045 with a small amount of emissions remaining from the aviation and international marine sectors which will need to be offset.

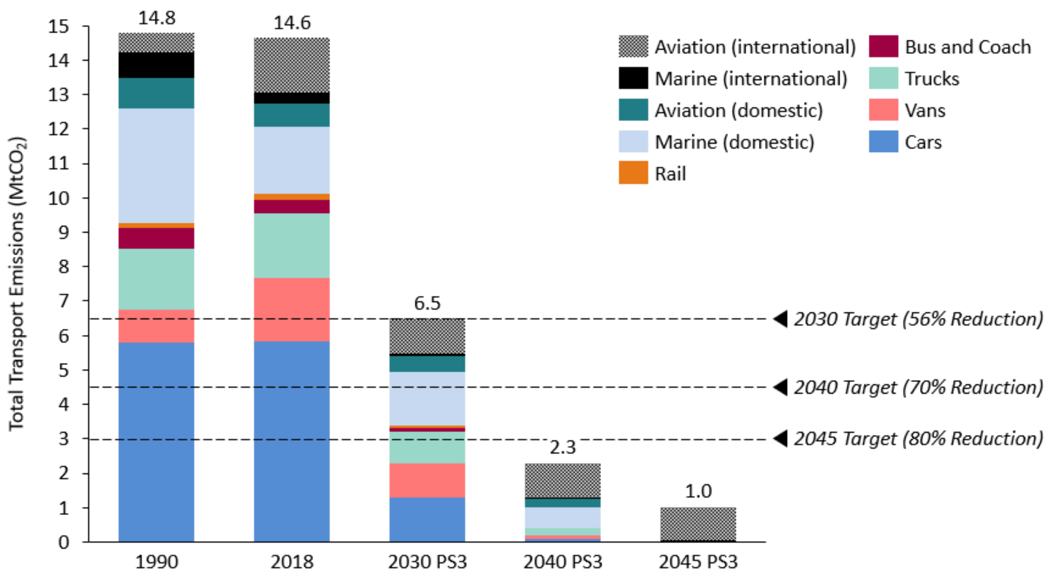

Figure 23: Summary of emission reduction achieved in Policy Scenario 3

Table 3 summarises the emission reduction effort across sectors. By 2030 the leading sectors are cars, driven by technology and behavioural change; buses, driven by technology change; and international marine, driven by behavioural change. The sectors doing their fair share include rail, vans, and trucks, while the sectors falling behind due to limited technology progress to date include aviation and domestic marine. Overall, the sectors not contributing a 56% reduction in emissions by 2030 include:

- Aviation, which achieves significant emission reductions in 2030 due to behavioural change, but the introduction of zero-emission planes does not ramp up till after 2030 and SAF supply will still be constrained by 2030 limiting the sector's ability to hit the 2030 target.
- Rail, which makes good progress towards the introduction of zero-emission vehicles but is affected by the significant increase in demand for rail travel in PS3. Overall, this has a limited impact as rail emissions are a very small proportion of the total and the savings made by shifting car journeys to rail are worth the resulting impact on rail emissions.
- Vans struggle to meet very high emissions reduction by 2030, relative to 1990, largely due to the large growth in the sector since 1990 and the expected continued growth out to 2030. The sector also struggles to achieve any meaningful modal shift as there are limited options for this for many van users.
- Trucks achieve significant emissions reductions by 2030 but do not hit a 56% reduction target due to the immaturity of the technology today. The majority of emissions abated from trucks are from shifting freight to rail and reducing the demand through logistics efficiency improvements, as emitting trucks continue to be sold until 2035.
- The domestic marine sector is dominated by the freight movement of fossil fuels and emissions from fishing vessels. The movement of fossil fuels are assumed to decrease over time as the demand for fossil fuels from transport falls. However, the very limited progress that has been made to date on developing zero-emission ships means that zero-emission ships are only just entering the market in 2030 and will have had minimal impact on reducing emissions by the 2030 target.

Table 3: Summary of emission reduction effort across sectors, relative to 2018

Sector	Emissions Saving by 2030 (%)	Emissions Saving by 2040 (%)	Emissions Saving by 2045 (%)
Car	78%	98%	100%
Bus and Coach	79%	96%	100%
Rail	42%	100%	100%
Vans	47%	95%	100%
Trucks	52%	89%	100%
Aviation Domestic	33%	67%	100%
Aviation International	33%	34%	36%
Marine Domestic	22%	70%	100%
Marine International	84%	88%	92%

Meeting these emissions targets include many technological, behavioural, and political risks that must be overcome to deliver this transition. The key risks are summarised below.

Car

- There is a political risk that these changes will be unpopular with some sectors of society.
- There is a risk zero-emission vehicles continue to be used in lower annual mileage applications focused on cities where they offset a small proportion of fossil fuel car emissions.

Bus and Coach

- Insufficient government investment in delivering a zero-emission world class public transport network will make it impossible to deliver a viable alternative to cars, limiting both car and bus decarbonisation efforts.
- Zero-emission coaches will rely on public refuelling infrastructure, delays to infrastructure rollout due to a lack of a technology winner risks delaying zero-emission vehicle introduction.

Rail

- Insufficient government investment in delivering a zero-emission world class public transport network will make it impossible to deliver a viable alternative to cars and domestic aviation, limiting both car, plane, and train decarbonisation efforts.

Vans

- There is a risk zero-emission vehicles continue to be used in lower annual mileage applications focused on cities where they offset a small proportion of fossil fuel van emissions.

Trucks

- There is a risk that rail freight capacity will not grow fast enough to take on many of these longer truck journeys.
- There is a risk freight decarbonisation continues to focus on vehicles and warehouses and does not address the question of what is being moved, why is it being moved and could these movements be made more efficient (e.g., by reducing food waste).
- To reach maximum decarbonisation of the freight sector requires collaboration between competitors to ensure the maximum amount of goods is moved on the minimum number of vehicles. There is a risk that competition laws and company self-interest limit the realisation of these opportunities.
- The lack of a clear technology winner will delay investment in public infrastructure, which risks delaying the rollout of zero-emission technologies on the larger vehicles, which are disproportionately responsible for emissions.

Aviation Domestic

- There is a technology risk that SAF and later zero-emission planes are not developed and scaled up to commercial scale quickly enough.
- There is a risk that alternative modes such as rail do not scale up capacity sufficiently to allow modal shift.

Aviation International

- There is a technology risk that SAF is not developed and scaled up to commercial scale quickly enough.
- There is a political risk that no government will take responsibility for international emissions unless a global agreement is reached.

- As regular plane travel is focused on high income groups there is a risk small financial drivers will be ineffective.

Marine Domestic

- There is a technology risk that zero-emission vessels are not developed in time for the existing fleet to be retrofitted in time.

Marine International

- There is a political risk that the treasury will be unwilling to give up income from fossil fuel production.

3 COVID Scenarios: Scenario Building and Results

3.1 Introduction

After the original study was completed, which developed the findings on PS3 presented in the previous Chapter, the world was overtaken by the COVID 19 pandemic, and the transport sector was drastically changed. Transport Scotland therefore commissioned Element Energy to complete a follow-on study looking at the potential impact of the pandemic on Scotland's trajectory to net-zero as set out in PS3. This chapter sets out the approach taken and the findings of this further work and provides insight as to how the COVID pandemic will impact Scotland's trajectory to net-zero and will help policy makers adjust their response in order to maintain a trajectory to net-zero despite the pandemic disruption.

3.2 Approach

At the time of writing the COVID pandemic was still affecting large parts of the world and Scotland was still under national lockdown. How Scotland will transition out of lock down is very uncertain and predicting the long-term impacts of the pandemic on travel behaviours and demand is subject to a high degree of uncertainty. In order to address this uncertainty and learn lessons about Scotland's possible transport futures we developed the following approach.

1. **Scenario Development** – Four very different scenarios, summarised in Figure 24, were developed in order to understand the full breadth of impacts the pandemic could have on the PS3 pathway to net-zero. These scenarios are not designed to be predictions of the future but instead present a breadth of different possible futures and the actual future is expected to lie between the 4 scenarios modelled here.
2. **Scenario Building** – Once a scenario was described in detail the scenarios were built by creating a long list of expected pandemic impact areas (e.g., working from home). For each scenario, the expected influence (high, medium, or low) of each impact area on a range of behavioural changes (travel demand, modal shift etc.) was assigned. For example, working from home is expected to have a high impact on travel demand under the "Local Economy" scenario but no impact on modal shift. The impact of all the different behaviour changes were then added together to get a scenario wide change in travel demand, travel by mode, freight demand etc.
3. **Scenario Modelling** – Once all the scenario inputs were finalised the output of the Scenario building exercise was an expected impact in total kilometres travelled by each mode and the expected change

in modal share. These finding were plugged into the Scottish transport emission model to understand the changes in emissions relative to the PS3 baseline.

3.2.1 Scenario Development

This analysis started with a review of the literature which found that the factors that are expected to lead to the greatest uncertainty in the post pandemic future are severity/length of the pandemic and the human (government, industry, individual) response to recovering after the pandemic. Four scenarios were therefore developed along these two axes, as summarised in Figure 24.

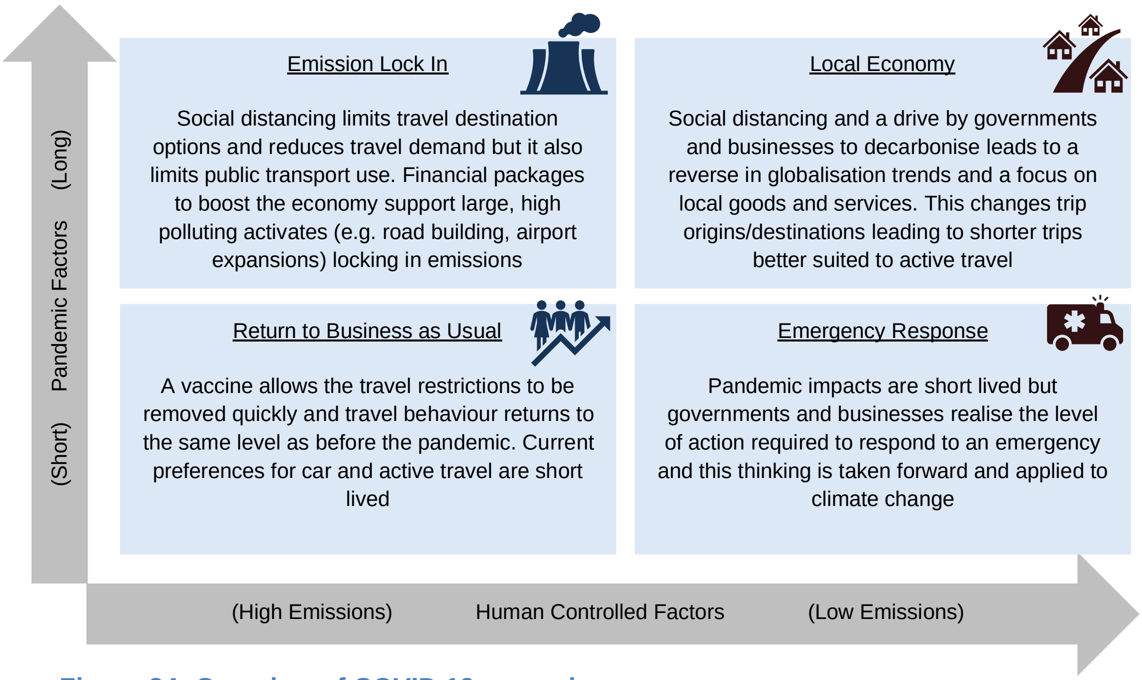

Figure 24: Overview of COVID 19 scenarios

Table 4 gives a more detailed overview of the three key scenarios (Emissions Lock In, Local Economy, Emergency Response), which represent a significant change from business as usual. Table 4 describes factors which directly impact emissions and are captured in the modelling such as the economic impact, but also less quantifiable factors such as culture change, which have been included to help the reader understand the alternative future described by the scenario but are not modelled. It can be observed from Table 4 that no single scenario has all red or all green boxes showing how all scenarios have a mix of emission positive and emission negative behaviours which partially cancel out resulting in smaller emission impacts from the scenarios than might have been imagined.

Table 4: Detailed summary of COVID 19 scenarios (Green or plus = change leads to a decrease in emissions. Yellow or circle = change leads to a small increase/decrease in emissions. Red or minus = change leads to an increase in emissions)

Themes	Emissions Lock In	Local Economy	Emergency Response
Economic Impact	Pandemic factors prevail, with a second wave further impacting the economy	Pandemic factors prevail, with a second wave further impacting the economy	Introduction of a vaccine/other means economic impact is short lived
Total Travel Demand	+ Reduction in travel demand in line with economic impact	+ Biggest reduction in travel demand	O Initial reduction, but recovers quickly
Policy Drivers	- Financial packages support high polluting sectors	+ Drive from governments and businesses to decarbonise	+ Drive from governments and businesses to decarbonise
Functionality of urban centres	- City centres are avoided, people drive out of town for shopping and leisure activities	+ City centres are avoided, shopping and leisure activities are completed locally, reached via active travel	O City centres are still used for shopping and leisure activities
Willingness to share space	- Social distancing measures means that the shift from public transport to private cars is permanent	O Shift from public transport to private cars, but government invest heavily in socially distanced public transport	+ Public transport is prioritised once social distancing is relaxed
Travel destination options	+ Destination options are limited due to	+ Destination options are limited due to social distancing	-

	social distancing measures	measures. Presence of local activities support active travel	National and international travel is widely resumed
Culture Change (consumption)	- High consumption of goods and services in society remains	+ Overall reduction in consumption levels and consideration of the carbon intensity of one's lifestyle	+ Overall reduction in consumption levels and consideration of the carbon intensity of one's lifestyle
Culture Change (health)	+ Concerns about health (chronic disease e.g., diabetes + asthma) leads to a push to reduce AQ emissions and increase active travel	+ Concerns about health (chronic disease e.g., diabetes + asthma) leads to a push to reduce AQ emissions and increase active travel	O Easing of pandemic means health concerns are less of a priority

3.2.2 Scenario Building

Once a scenario was described in detail the scenarios were built using the following method:

1. Correct the baseline demand based on the length of the pandemic. For the short pandemic scenarios, we have delayed the growth in demand by 5 years, this means the travel demand projected for 2020 in 2019 will now not be seen until 2025 as demand dips and then recovers. For the long pandemic scenarios, we have delayed the growth in demand by 10 years.
2. A long list of expected pandemic impact areas was created that could be input into our emissions model, see next page.
3. For each scenario, the expected influence (high, medium, or low) of each impact area on a range of behavioural changes (passenger modal shift, passenger travel demand domestic, passenger travel demand international, freight modal shift, freight travel demand domestic, freight travel demand international) was assigned.
4. The high, medium, and low levels of influence were assigned an expected percentage change in behaviour by 2030. The influence was assigned as Low = 2%, Medium = 5%, High = 10%. What this

means is that if working from home is assigned a high impact level in the "Local Economy" scenario then we expect that the passenger commuting demand will be reduced by 10% in 2030 relative to the business-as-usual scenario.

5. Sectoral impacts such as a 10% reduction in commuting demand are converted to an impact on overall passenger or freight demand by correcting for how much of total demand is made up of a specific behaviour (commuting).
6. Finally, all the impacts, both negative and positive, for the behavioural changes (passenger modal shift, passenger travel demand domestic, passenger travel demand international, freight modal shift, freight travel demand domestic, freight travel demand international) can be added up before being fed into the model.
7. The model is then run to understand the impact on emissions relative to PS3.

The scenario input factors considered included:

Zero-emission vehicle uptake

- Supply Impact: Reduced vehicle sales, production line halt, major economic hit for OEMs
- Demand Impact: Reduced fleet upgrades due to economic down-turn

Passenger trip frequency and length

- Less commuting trips are made due to home working
- Less business travel due to the rise of videoconferencing
- Fewer university students due to travel restrictions/more virtual learning
- Fewer shopping/leisure trips due to economic downturn for retail and leisure industries
- Shift from international to domestic holidays
- Private companies with emission standards/ targets accelerate behavioural change to decarbonise business trips

Passenger trip mode

- Fewer people are willing to use public transport
- More trips are taken by active travel

Freight, shipping, and aviation

- Thriving freight transport businesses upgrade to clean vehicles
- Change in demand for freight transport

- Fewer flights during economic down-turn for the aviation industry due to travel restrictions

Infrastructure

- Reallocation of road space in cities to active and public transport
- Delay/Stop to airport expansion
- Localisation of goods and services as people avoid big gatherings (e.g., supermarkets and shopping malls) and governments aim to stop the spread of infection from localised pockets

3.3 Results

The main impacts of the COVID-19 pandemic on behaviour and emissions are expected to be felt in the 2020s. Later in the timeline to 2045 other factors will overshadow the impact of the pandemic and the shift to zero tailpipe emission vehicles will begin to offset difference in behaviour between the scenarios. Figure 25, therefore, shows the breakdown of emissions for the different scenarios in 2030 when the greatest difference between the scenarios is expected to be felt.

Given the very significant impact the pandemic has had on everyone's lives the difference between the scenarios may at first appear to be quite small. However, at these levels of changes in behaviour and technology, where every opportunity has been taken to reduce emissions, there are no low hanging fruit option to reduce emissions further. This means overcoming an additional 1Mt CO_2 to bring the Emission Lock In scenario back on track to meet Scotland's 2030 transport emission envelope would require enormous effort. For example, this increase (1 Mt CO_2/year) in emissions is almost equivalent to the emission saving from all the car behavioural change outcomes proposed in Chapter 2.

One of the key reasons why the pandemic is not expected to radically increase or decrease emissions is because it is very unlikely that we transition to a future where predominantly emission positive or emission negative changes prevail. Instead, what we see is that most changes that are positive for emissions are likely to coexist with changes that are negative for emissions (e.g., the pandemic may increase the number of people working from home, especially in higher income sectors, reducing commuting trip frequency; however, at the same time these people may choose to move further away from work looking for cheaper housing and more space. This move away from urban centres will lock in car dependency and longer trip distances not just for commuting trips but for all trips, potentially offsetting any emissions benefits) meaning the net emissions impact of the pandemic in 2030 is smaller than first expected.

In all scenario's emissions are reduced due to the economic shock of the pandemic which is expected to slow the growth in travel demand. However, the Emission Lock In scenario and the Local Economy scenario show impacts well beyond just economic changes to significant changes in policy and behaviour.

In the case of Emission Lock In we see a significant reduction in overall travel demand due to the long pandemic, but this is more than compensated for by:

- Strong economic recovery packages for the aviation industry and airport expansions accelerating aviation recovery and future growth;
- Increased road building and a lack of infrastructure investment in options for modal shift (e.g., multi-modal hubs to put road freight onto trains, rail line upgrades, buses, cycling and walking space), which increases the relative share of cars, vans and trucks;
- The car industry successfully lobbies government to allow a 5-year extension to the phase out date on the sale for hybrid and PHEV cars, vans, and trucks on the grounds that the pandemic has left limited resources for investment in zero-emission technologies.

Overall, these changes mean that while future travel demand growth has been significantly reduced emissions still increase by 15% between PS3 and Emissions Lock In.

In contrast the Local Economy scenario maintains positive behavioural change made during the pandemic by supporting change through investment in the right infrastructure. This is not to say that for many people life will not go back to including the wide range of activities enjoyed before the pandemic but that the most wasteful habits of the pre pandemic world do not return after the pandemic and new opportunities are seized upon. The main changes include:

- Many companies enact net-zero targets and accelerate their transition towards these targets by replacing some of the international meeting attended by very frequent flyers with teleconferencing earlier than they would have done without the pandemic.
- Increases in working from home frees up city centre office space, combined with increasing retail space left empty by the pandemic, allows planners to re design urban areas for dense mixed use walkable neighbourhoods, eliminating car use for shopping and commuting journeys for local residents.

- Recovery infrastructure funding is focused on scheme which support modal shift to public and active travel for passengers and to rail for freight.

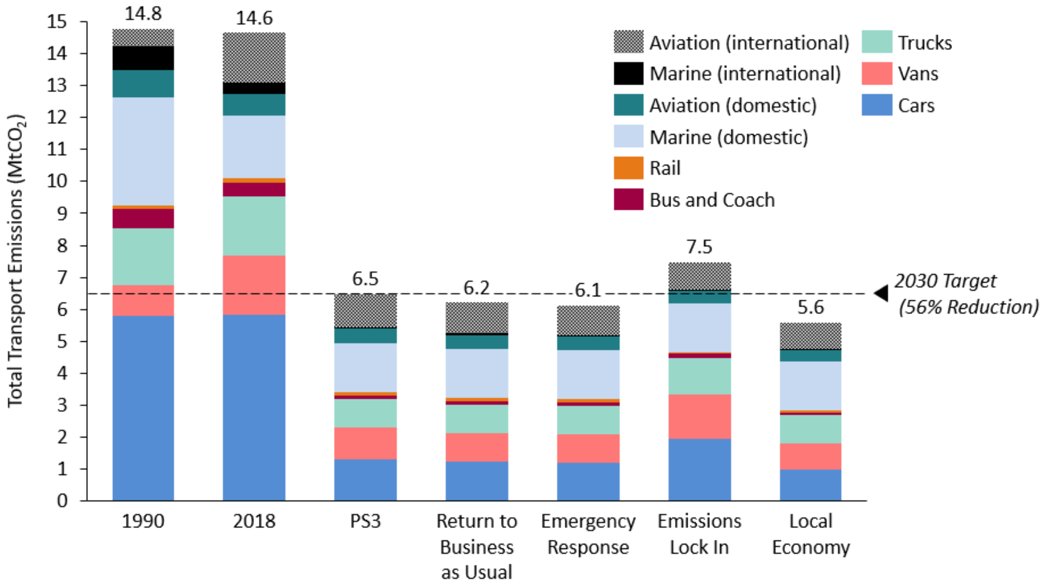

Figure 25: Overview of COVID scenario results in 2030

What these two scenarios show is that the long-term impact of the pandemic is not defined by the pandemic but by the way in which government, business and individuals decide to respond to the pandemic. This means our response to the pandemic can significantly help our hinder our effort to decarbonise in a fair and equitable manner. The largest impact of the pandemic is expected to be the way in which government decide to spend the recovery budget to boost growth. If these investments focus on activities such as road building, airport expansions, out of town shopping centres, car centric housing estates, and North Sea oil and gas extraction then the long-term impact of the pandemic will have been to increase emissions and make meeting the decarbonisation target much harder. If, on the other hand, the invest focuses on activities such as rail infrastructure, pavements, cycle lanes, bus lanes, zero-emission public transport vehicles, city centre revitalisation, improving and repurposing existing building to provide local services, and freight urban consolidation centers then the long-term impact of the pandemic will have been to decrease emissions and accelerate the decarbonisation transition.

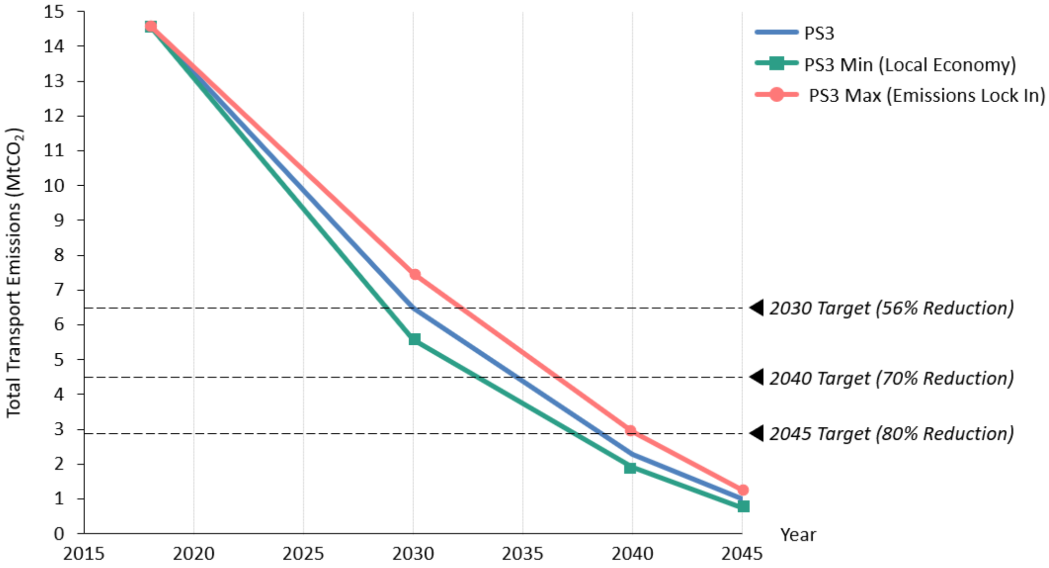

Figure 26: COVID scenarios emissions impact

4 Scenario Implications on Cost and Equity

The main focus of this study is transport emissions but to ensure a just transition to a low carbon economy it is also important to consider the cost and equity implications of the scenarios. For a detailed analysis of the cost and equity impacts of the scenarios a full set of policies needs to be agreed upon. As the design of the policy packages for meeting Scotland's net-zero target will follow this work, it is not possible to consider the cost and equity impacts in full, so the analysis here is necessarily at a high-level.

4.1 Cost Impacts

As this study does not set out the policies required to meet the net-zero target, the cost of the policies to government cannot be calculated, neither can the cost of the scenarios to the general public or the wider economy. However, Element Energy and Cambridge Econometrics have completed a study for Climate X Change on the economic impacts of Ultra-Low Emission Vehicle (ULEV) adoption in Scotland (Identifying the economic impact from ULEV uptake). The study concluded that the overall economic impact of a switch to ULEV vehicles will be positive for Scotland, with the jobs and revenue lost from current vehicle production and maintenance, petrol station operation and fossil fuel extraction/distillation and distribution more than offset by new jobs and revenue produced from ULEV production and maintenance, ULEV infrastructure rollout and ULEV fuels production. The lower cost of owning and operating ULEV vehicles also leads to higher consumer expenditure in other areas of the economy with associated benefits.

The study for Climate X Change did, however, highlight that jobs and revenue from fossil fuel vehicles will be lost in the near term and it will take time for these to be replaced by new jobs and revenue from the low emission alternatives. Successful government support through the transition phase is therefore vital to ensuring minimal adverse impacts. Advanced planning is also very important, for example the largest loss of jobs from the transition comes from current vehicle maintenance. However, effective planning to ensure new people entering this job market are trained on zero-emission powertrains and a clear strategy that provides retaining opportunities and matches the natural turnover of the workforce over the next 20 years with the changeover of the fleet, can help to avoid job loss while transitioning the sector over to new fuels as they enter the market.

This analysis, for Transport Scotland, included an assessment of the total expenditure on road vehicles (car, van, bus, coach, truck) CAPEX between the three core scenarios over the next 10 years, as set out in Figure 27. This shows that total vehicle costs and therefore total government subsidies are significantly lower for scenarios which rely on shared and public transport rather than relying on the current private transport dominated system. This trend is also expected to hold true for charging infrastructure where it is more cost effective to install infrastructure for smaller shared/public fleets rather than a large private fleet.

Assuming that Scotland continues to support zero-emission vehicle purchase over the next decade, this is expected to be needed to encourage supply into the market and increase demand, then it is clear from Figure 27 that the cost of vehicle and infrastructure grants to government will be lowest in PS3. Choosing to pursue a technology and behavioural change scenario such as PS3 rather than a technology-focused scenario such as PS1 therefore offers a cost saving from reduced vehicle subsidies, which could be used to support the cost of the behavioural change aspects of PS3.

Beyond the high expense to government of PS1, a vehicle technology-driven pathway also provides very little additional benefit to the Scottish economy making the cost benefit harder to justify. In contrast, shifting government expenditure away from vehicle subsidies to supporting behavioural change, as in PS2/3, is expected to provide multiple benefits beyond emission reductions. For example, PS3 requires high speed internet across the country to help people to work from home, good walking and cycling infrastructure to encourage greater use of active transport, and better public transport infrastructure to encourage fewer people to use private cars. All of these changes can provide broader benefits than just reducing greenhouse gas emissions. This means following PS3 can support better public health, reduce congestion, and provide more human-friendly public spaces, along with a wide range of other benefits and is therefore likely to provide the greatest overall benefit to the Scottish economy.

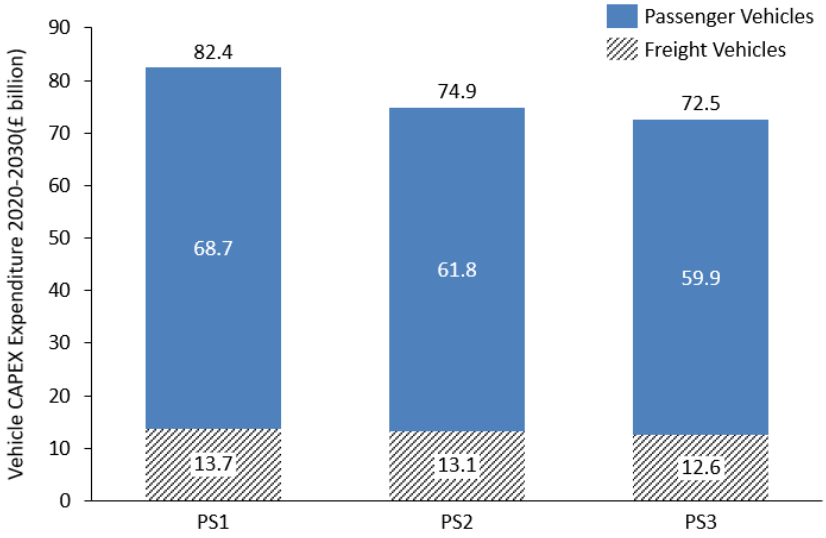

Figure 27: Total vehicle (car, van, bus, coach, truck) CAPEX investment in Scotland between 2020 and 2030

4.2 Equity Impacts

The transition required for Scotland to meet its net-zero targets will have major impacts on people's everyday lives, in terms of their access to goods and services, public health and their finances. Good policy can help to ensure that the benefits of decarbonisation are spread across all sectors of society and that the costs of decarbonisation do not fall unequally on specific groups of people. This section highlights some of the areas where the transition will affect the equity of the transition to help policy makers focus policy support in the right areas.

Currently the transition to zero-emission vehicles is focused in richer urban areas. This is because richer consumers purchase new vehicles, infrastructure rollout is better in more densely populated regions and electric cars have historically had a short range suited to urban driving. This means the benefits of zero-emission vehicles such as reduced air pollution, low noise, low running costs etc. are not shared equally and it is often poorer regions, where the oldest, most polluting vehicles are driven, that continue to suffer from poor air quality the longest. By supporting greater use of public/shared/active transport (PS2 or PS3) Scotland can break this trend as rich and poor communities will both be provided with access to easily accessible, zero-emission, affordable public/shared/active transport options that have a much lower impact on the local environment they pass through.

The decarbonisation of different sectors is moving at different rates. For example, the bus sector is on the verge of a very quick decarbonisation transition as zero-emission vehicles are introduced but the aviation sectors will not achieve significant emission reductions at anywhere near the same rate, in the short term, due to a lack of technology readiness. Regular flying (flying multiple times per year) is a privilege of the richest people in society whereas regular bus use is much more common in poorer demographics. Governments must ensure that these difference in technology readiness do not lead to the poorest in society paying for the early decarbonisation of transport while richer groups do not pay the full economic cost of their pollution until much later in the transition.

Policies impacting travel behaviour are likely to be viewed negatively by groups campaigning for improved mobility and access to services for currently disadvantaged groups as they fear changes in travel behaviour will impact these groups the most. However, behaviour change policies can achieve nation-wide changes in travel patterns by not just reducing travel demand but by helping to redistribute current travel demand more equitably. For example, climate behavioural change policies could still encourage increased car travel for some disadvantaged groups while reducing overall car travel demand.

Major roads, which often lack pedestrian crossings and sufficient space for active travel modes, act as a barrier to people moving between local regions causing isolation and reducing access to local goods and services. This impact is especially a problem for disabled people. The redesign of road space and layout to provide more space for public and active modes for PS2 or PS3 is an excellent opportunity for wider changes to make the regions easily traversable by people with a physical disability. Some of the policies, such as reduced road speed, more space for active travel and less space for private cars, that could support the transition to PS2 or PS3 have already been enacted in European cities. These policies have allowed Oslo and Helsinki to achieve no pedestrian road deaths in 2019 (see Smart Cities World, 2020, Drivers are guests': How Oslo cut traffic deaths to almost zero in 2019), highlighting the improvement in the city scape for vulnerable groups such as the very young, very old and disabled people who are the most likely to be the victims of road accidents.

Land-use planning is a very important policy lever for controlling travel demand. Land-use in existing urban areas is often overlooked in travel planning because it is assumed that the land-use will remain the same for the lifetime of the buildings. Building replacements happen over such long times scales that it is difficult to include this in transport planning which must keep up with much more rapid changes. However, several cities around the world have started to look at changing land-use over much shorter time periods by repurposing existing buildings and this thinking is beginning to become a central part of Scotland’s future land planning with the Programme for Government 2020 committing to take forward ambitions for 20 minute neighbourhoods (see ClimateXChange, 2021, 20 Minute Neighborhoods in a Scottish Context). Examples from around the world include (see CityLab, 2019, Paris Major: It's time for a 15 minute City):

- Barcelona's Superblocks which discourage car use in local areas and encourage the growth of local retail and entertainment.
- Portland Oregon in the USA aims to cover 90% of the area in "20-minute Neighbourhoods" where all basic needs except employment can be reached in a 20-minute walk from home.
- Melbourne Australia has been trialling "20-minute Neighbourhoods" since 2018.
- In her re-election campaign Major of Paris Anne Hidalgo has proposed a "15-minute city" plan which aims to provide work, shops, entertainment, and healthcare within a 15-minute walk or cycle of people's homes.

Reimagining land-use in this way provides opportunities to improve access to goods and services to those who currently lack opportunities because travel costs are high or easy access to goods and services is restricted by their home location. This idea can also be applied to rural communities where goods and services can be reintroduced to reduce travel demand and to improve people's everyday lives.

One policy to encourage the shift to low emission vehicles is the introduction of Low Emission Zones. These could be updated to support the shift to zero-emission vehicles by developing Zero Emission Zones. These policies are very effective at changing people's buying decisions but, because they impact the whole stock, they have a disproportionately negative impact on poorer communities and small businesses who often buy second-hand vehicles and are not in a financial position to buy a new zero-emission vehicle to become compliant. However, good policy design to exempt certain groups from the zone or to provide additional financial support for these groups in the run up to the implementation of a zone can alleviate these issues (see Transport and Environment, 2019, Low-Emission Zones are a success - but they must now move to zero-emission mobility).

The shift away from fossil fuels will have a disproportionately high impact on Aberdeenshire where a high proportion of jobs and income are related to the production of North Sea Oil and Gas. The reduction in the use of fossil fuels in Scotland, and globally, is likely to impact the number of jobs available in Aberdeenshire. This impact could be partially alleviated by supporting the Carbon Capture, Utilisation and Storage (CCUS) industry, which could make use of some of the infrastructure and skill in Aberdeenshire in a low carbon economy. This also opens up the option to produce hydrogen from North Sea natural gas through natural gas reforming and then to store the CO_2 emissions from this process in the North Sea, enabling large scale hydrogen production for transport, industry, and heating.

While it is important to manage the loss of jobs and economic output in Aberdeenshire, the shift from oil and gas to renewables also offers the opportunity for all areas of Scotland to become energy producers, spreading the economic benefits that used to be concentrated in one region across more of Scotland (the reduced profitability of North Sea oil and gas over time means that Aberdeenshire will still need to transition it economy away from fossil fuel production even if Scottish climate emission targets had not been set). The local production of renewable electricity, that can be used as a transport fuel, offers great opportunities for rural communities in Scotland, which often have high renewable production potential and currently suffer from limited access to petrol and diesel refuelling options. By switching to electric vehicles, rural communities will be able to refuel vehicles at home or locally, which for many will be an improvement over current refuelling station access. The only knock-on effect of the transition will be that local shops which are paired with a refuelling station will lose income and could close. A policy such as the Rural Petrol Station Grant Scheme, that has been run in Scotland in the past, could be reintroduced to help local amenities provide services relevant to Scotland's future low carbon economy, helping them to stay financially viable in the future.

Zero-emission vehicle supply is a major barrier to Scotland meeting its emission targets. As Scotland and other countries set more stringent emission targets there is expected to be an increasing global demand for zero-emission vehicles that continues to exceed supply. Scotland currently has expertise in the production of low volume vehicles which require a high number of person hours in the production, such as buses, coaches, and ferries. The decarbonisation of transport globally will offer Scotland the opportunity to further develop its vehicle production and export capacity in zero-emission low volume production vehicles such as buses, coaches, trucks, trains, and ships. With Scottish Government support this could offer new jobs in areas where industry jobs have been in a long-term decline helping in the economic recovery of economically disadvantaged regions.

5 Recommendations and Barriers to the Net-Zero Transition

This project focuses on the policy outcomes needed to meet the net-zero target and does not specifically set out recommended actions/policies needed to achieve the policy outcomes. However, this chapter provides a high-level overview of the lessons learned from the analysis in terms of key actions and barriers that need to be considered when Scotland is planning its net-zero transition.

5.1 Introduction of Zero-Emissions Vehicles

Key high-level actions that need to be considered when planning the transition of the fleet to zero-emission vehicles include:

- Supply of zero-emission vehicles. Current manufacturing supply of zero-emission vehicles is insufficient to meet current demand (cars and vans) or a sudden increase in demand (all other vehicle segments). Without a national OEM for cars or vans it is likely that Scotland will have to continue to support zero-emission vehicle sales through grants and subsidies for a significant period of time to help draw supply into the market. For larger vehicles such as trucks, buses, trains, and ships, which are produced in much smaller volumes and involve a larger proportion of hand fabrication, Scotland should support national production and retrofits to help meet supply. Early supply can also be boosted by collating orders so that one large order is agreed. This helps to ensure the order is prioritised and can provide cost benefits.
- Demand for zero-emission vehicles. The demand for zero-emission cars and vans is beginning to grow, and will continue to do so, as the prices come down and more vehicle models are offered. The uptake of these vehicles can be supported by the continuation of current policy and a clear end date for the sale of fossil fuel powered vehicles. However, other vehicle segments such as trucks, planes and ships are at a much earlier stage in the transition and considerable work is still required before fiscal policies will effectively encourage uptake; for example, in demonstrating the technology through commercial trials and educating operators through demonstrations and information campaigns.
- Infrastructure for zero-emission vehicles. A clear infrastructure plan that sets out the minimum number of refuelling sites/locations, capability and installation dates can help people, especially businesses, to plan the introduction of zero-emission vehicles.
- Rural communities. Currently the introduction of zero-emission vehicles is focused around urban areas, predominantly because

policy has historically been driven by air quality. However, to ensure that the benefits of emission reductions reach rural communities and to prevent rural communities from being stranded without refuelling options during the transition, the rollout of zero-emission cars should be focused in rural areas, while urban areas focus on a shift to public, active, and shared transport.

- UK wide agreements. Scotland must work with the rest of the UK to ensure all regions are moving towards a similar set of policy outcomes. This will help prevent issues such as Scottish residents travelling into England to purchase a fossil fuel powered vehicle after their sale has been stopped in Scotland.

Key barriers to transitioning the fleet to zero-emission vehicles include:

- Supply of zero-emission vehicles. With a more ambitious climate target than many regions and very limited control over zero-emission vehicle supply at a European level there is a risk that supply of zero-emission vehicles hampers Scotland in meeting its targets. Scotland can help to overcome this by providing strong fiscal incentives that guarantee a market for zero-emission vehicle sales. However, the level of fiscal support required to ensure zero-emission supply will be higher than the level required to make the vehicles cost effective for consumers making this an expensive policy option for Governments.
- Policy control. With several major policy levers such as vehicle tax set at a UK level, Scotland must work closely with the rest of the UK to ensure that the whole of the UK moves towards the net-zero targets in a consistent manner and that UK policy does not hinder Scotland in meeting its more ambitious net-zero targets.
- Unclear optimal zero-emission technology pathway. Several vehicle segments such as trucks and ships could make use of several different zero-emission fuels. Due to the immaturity of these markets, it is currently unclear which fuel will become the dominant fuel in each market. This uncertainty delays infrastructure rollout and investment and could be a major barrier to Scotland meeting its targets given the short timeframes available. Overcoming this will require agreements between multiple nations in a region to ensure a common zero-emission refuelling option is available in all countries so that vehicles can pass freely between countries without refuelling barriers.
- Carbon leakage. The difference in the timeline for the introduction of zero-emission vehicles between vehicle segments and between countries could lead to carbon leakage without proper control. For example, setting more ambitious targets for the introduction of zero-

emission vehicles or for behavioural change for cars than vans could lead to a shift in buying behaviour away from cars towards small vans. Similarly, stronger targets for trucks, ships, and planes in Scotland than in other countries could lead to these vehicles refuelling in other countries and travelling into Scotland.

5.2 Changing Passenger Travel Behaviour

Key high-level actions that need to be considered when planning to support a shift in travel behaviour towards greater use of public, active, and shared transport include:

- Support flexible working. Where possible flexible working conditions should be supported to allow people who commute by car to work from home part of the time. This requires employer support, good internet access in homes and the rollout of software and hardware equipment to support high quality teleconferencing.
- Good land-use planning. Land use changes over long time-cycles but new developments should be designed to reduce car dependencies and old areas can be improved by ensuring goods and services such as shops, office space, entertainment sites etc. are added where missing by repurposing existing buildings. This could follow the “20-minute neighbourhood” plan discussed under Equity Impacts.
- Reduce trip lengths. Mixed developments and strategies such as the “20-minute neighbourhood” help to reduce trip lengths and in so doing make the trips much more suitable to walking, cycling and public transport. This combined effect helps to significantly reduce the emissions from these journeys.
- Plan the public transport network. The current bus network in Scotland is largely decided based on commercial viability alone. If urban Scotland is going to rely more on public transport, routes must be planned centrally to ensure good network access to all communities and integration between transport routes and modes.
- Plan the active transport infrastructure network. Active transport highways that help to speed up active transport journeys can be an important incentive to encourage people to view active transport as more convenient than private cars. This network needs to be extensive, supporting not just inner-city travel but also e-bikes for inter-urban routes and walking and cycling to local shops in rural areas.
- Reduce the convenience of private car use. Cities such as Paris and Oslo that have managed to reduce reliance on the private car have invested in alternative transport modes, but they have also reduced

the convenience of private car use by removing road and parking spaces, reducing car speed limits, and forcing cars to drive around the city centre instead of being able to pass through it.

- Ensure the cost competitiveness of public transport. Electrification and automation of cars could bring down the cost of travel. To ensure this does not result in a major shift away from public transport, public transport subsidies and car taxation must be used to ensure public transport remains a cost-effective means of travel.
- Increase vehicle sharing. Vehicle sharing is a potentially low cost and quick measure that can have a significant impact on vehicle km travelled and emissions. An important first step in achieving this change is to ensure all future traffic and emission targets focus on the movement of people not vehicles. The Scottish Household Survey results suggest that private car occupancy rates in Scotland are as low as 1.2 – 1.5. Other countries with lower car ownership rates and therefore higher car sharing needs demonstrate much higher levels of sharing. For example, Romania has an occupancy rate of 2.7, demonstrating that it is possible to make much more effective use of a smaller car fleet (see Davide Fiorello, Angelo Martino, Loredana Zani, Panayotis Christidis, Elena Navajas-Cawood; 2016, Mobility data across the EU 28 member states: results from an extensive CAWI survey). The drive to sharing will be supported by the introduction of MaaS and the wider rollout of services such as Uber Pool but ride sharing between family, colleagues and neighbours could be encouraged sooner through schemes such as workplace parking levies and high occupancy lanes.
- Focus investment away from roads towards public, active, and shared transport. The cost benefit analysis conducted to justify current road building projects assumes vehicle km travelled will increase and that the road will provide benefits in terms of reduced congestion. However, to meet Scotland's emission targets will require a significant reduction in vehicle km travelled, alleviating congestion, and tipping the cost benefit analysis against future road building projects. This will help to reduce government spending on roads freeing up money for active and public transport infrastructure.
- Focus the limited BEV supply in the right markets. Some users such as taxi drivers and company car drivers drive significantly further than the population average. Ensuring these markets are early adopters of BEV can deliver significantly greater emission saving than if the same vehicles are purchased by lower mileage drivers.

Key barriers to shifting travel behaviour towards greater use of public, active, and shared transport include:

- Public opinion. Cities that have implemented strong measures to reduce car dependencies have initially faced very strong opposition (see Guardian, 2018, Paris: legal challenge to car-free promenade by Seine) and this can often derail these projects before they can deliver major benefits. However, in regions where plans have been completed and everyone has readjusted to the new transport system, public opinion often favours further car reduction measures (for example, Madrid banned cars in the city centre, this was later overturned by a new government, but the ban was put back in place after public backlash and legal challenge - CityLab, 2019, In Madrid, a car ban proves stronger than partisan politics).
- National versus regional control. Delivering the changes set out in this work will require a consistent approach between the UK Government, the Scottish Government and Scottish local authorities, as all three have control over policies that will be needed to bring about these changes.

5.3 Changing Freight Travel Behaviour

Key high-level actions that need to be considered when planning to support a shift in freight operating behaviour include:

- Support infrastructure for intermodal operations. Scotland's geographical position at the extremity of Europe means that a disproportionately high proportion of goods are moved several hundred km by a single vehicle in a single trip. This means there is a much better financial and operational case for use of rail for transporting a wide range of goods. However, to achieve this, upgrades are required to the West and East Coast Mainline routes to allow them to support more freight traffic. Scotland will therefore need to work with the rest of the UK to ensure rail upgrades are prioritised.
- Support economy wide not transport focused action. The freight sector provides a service to all other sectors of the economy. This means good practise in other sectors such as reduced food waste, reduced food packaging, reduced concrete use in buildings, long life consumer goods, refurbishing rather than replacing everything from electronics to building, local production, reduced fossil fuel use etc. all help to reduce freight transport demand and therefore emissions.
- Support the rollout of the physical internet and freight as a service. Currently in the UK 30% of all truck kilometres are run completely empty and of the other 70% of kilometres the average truck is filled

to between 50-60% of its maximum weight capacity. The introduction of the physical internet and freight as service aim to better match the movements of goods to vehicles helping to reduce these inefficiencies in the freight system.

Key barriers to changing freight operator's behaviour include:

- Competition. The introduction of intermodal freight transport and new concepts such as the physical internet and freight as a service all require coordination across multiple companies. For some companies used to operating an end-to-end service, working alongside competitors to provide a service will be very challenging.
- Actions needed across country borders. Most of the freight arriving and leaving destinations in Scotland has travelled from outside of Scotland. This means Scotland's freight system must seamlessly interlink with England's and with wider Europe. This will be a challenge if Scotland pushes to introduce a more efficient freight system ahead of other countries.

6 Conclusions

This study has analysed a range of scenarios including differing levels of zero-emission vehicle uptake and changes in travel behaviour to understand the magnitude and rate of change required for Scotland to meets its climate change targets. The main findings of the study are that the targets are very challenging and will require major changes in Scotland and commitment from the Scottish and UK Government. The study also showed that meeting the targets will require Scotland to make full use of all options to reduce emissions including the introduction of zero-emission vehicles and changes in travel behaviour and that focusing on one decarbonisation pathway or not exploiting a decarbonisation option to its full will mean Scotland misses its targets.

However, the findings also show that with strong national and political commitments the targets can be met and that the financial commitments made to reducing emissions can also lead to a wide range of additional benefits which will improve the lives of Scottish citizens and help Scotland to build a stronger economy in the future.

The additional COVID pandemic scenarios have shown that the core study findings are relatively robust and that the policy outcomes from PS3 developed before the pandemic are still the right policy outcomes to aim for after the pandemic, in order to meet Scotland's transport emissions envelope.

The main policy outcomes that Scotland needs to achieve to reach its climate targets are:

<u>Vehicle Technology Policy Outcomes</u>

- End the sale of fossil fuel powered cars and vans in 2030.
- Phase out the sale of the largest most polluting cars between 2020-2030.
- End the sale of fossil fuel powered buses in 2025 and start a retrofit program for older buses to install zero-emission powertrains.
- End the sale of fossil fuel powered trucks in 2035.
- Allowing existing UK policies to drive the uptake of biomethane powered trucks for the highest annual mileage applications.
- Ensure all trucks are retrofitted with the latest low aerodynamic and rolling resistance features by 2030.
- End the use of fossil fuelled vehicles on Scottish roads in 2045 (following the sales targets presented in the earlier points will remove almost all fossil fuel powered vehicles from the fleet through

natural fleet turnover by 2045. A five-year extension could be offered to some important fleets based in England).
- Replace all diesel trains with hydrogen or electric trains by 2035.
- Support the development, production, and certification of net-zero synthetic aviation drop-in fuels early in the 2020s, targeting a minimum of 10% Sustainable Aviation Fuels (SAF) blending by 2030, and push for their widescale rollout across Europe and globally.
- Support the development of zero-emission ship powertrains in the 2020s, complete trials of zero-emission ships by 2030 and end the sale of fossil fuel powered ships and begin retrofitting existing ship powertrains from the early to mid-2030s.

Behavioural Change Policy Outcomes

- The main transport mode for people moving within and between the urban regions of Scotland (this is assumed to include Edinburgh, Glasgow, Dundee, Aberdeen, and the satellite towns/villages that surround them) must switch from private cars to public/active and shared transport modes over the next decade.
- Walking must become the preferred mode of transport for short journeys and cycling (bikes and e-bikes) must be a viable mode for both urban and inter-urban journeys.
- The use of active, public, and shared transport must be encouraged and facilitated through excellent infrastructure, Mobility as a Service (MaaS) and preference in all transport and land-use planning decisions.
- The modal shift, along with destination shifting, journey shortening (facilitated through 20-minute neighbourhoods), journey avoidance (facilitated by teleconferencing) and car sharing, set out in the first three bullet points, must achieve a 20% reduction in the number of car kilometres travelled across the whole of Scotland between 2019 and 2030.
- This in turn will require a major increase in bus, coach, and train numbers. This needs to be overseen by government to ensure everyone has access to the public transport network but will partially be driven by industry as higher ridership rates improves the business case to provide the service.
- Shift the purchase of BEV and FCEV towards high mileage users (e.g., ensure that all taxi, private hire, and company car fleets are BEV/FCEV only by 2030).
- Increases in vehicle demand caused by the decreasing cost of electric fuels must be mitigated through a policy, such as road user

charging, which brings transport costs per km back up to current fossil fuel per km prices for driving.

- Limit the growth in van demand to 10% between 2019 and 2030, reducing demand by 7% in 2030 compared to the BAU scenario.
- 23% of freight goods moved by road must be shifted to rail and ships by 2030 (this is expected to be predominantly on longer routes and is equivalent to all road freight moved over 400km, although exact routes shifted to rail will depend on infrastructure). This means improving the freight train links between Scotland and England to allow them to take more of the cross-border freight movements and upgrading Scottish ports to allow greater freight movement capacity.
- Reduce truck tonne km by 15% by 2030 through a range of efficiency measures such as reducing food waste, improving product lifetime, optimising goods to vehicle allocation across and between fleets (backhauling, co-loading, physical internet).
- The emissions from the movement of fossil fuels by ship from Scotland to remote areas of the world such as South East Asia is assumed to reduce close to zero by 2030 through lower levels of production, decreases in exports and/or reduced carbon intensity of transportation.
- Emissions from domestic and international aviation need to fall by 33% between 2019 and 2030, driven by a mix of SAF and a reduction in total flight kilometres travelled.