UK Energy Research Centre

Transport Evidence Compendium

The purpose of this evidence compendium is to synthesise the findings arising from the UK Energy Research Centre's transport programme to inform the work of policy professionals and groups who engage in making transport zero carbon, cleaner and healthier.

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START

How To Use This Compendium

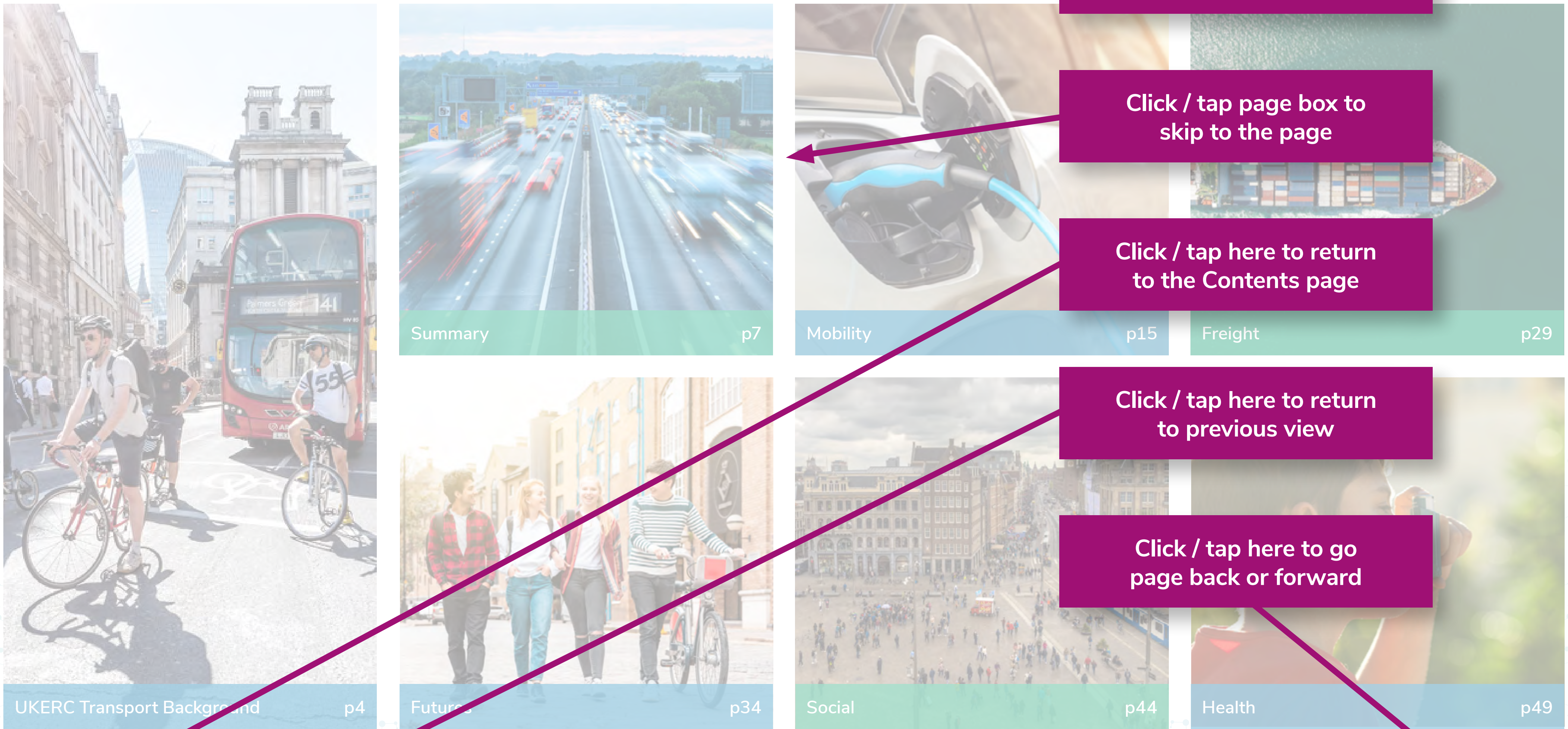
Click / tap on the tab to skip to a specific section

Click / tap page box to skip to the page

Click / tap here to return to the Contents page

Click / tap here to return to previous view

Click / tap here to go page back or forward



Contents

Background: The Challenge of Decarbonising Transport

The transport sector is responsible for 36% of UK carbon emissions. While other sectors of the UK economy have made some progress in reducing their greenhouse gas emissions since 1990, the transport sector, including both air and surface modes as well as domestic and international movements from the UK, has yet to do so. In 2019, emissions were 11% above 1990 levels compared to the 53% reduction achieved by the rest of the economic sectors (Fig.1).

Key challenge areas:

1. **Rising transport demand** is closely tied to population and economic growth, making reductions difficult without systemic changes. Globally, demand for goods and mobility is expected to more than double by 2050, outpacing technological decarbonisation advances.
2. **Oil dependency** across transport continues to remain high (98% in the UK) with low carbon alternatives like electric and hydrogen energy vectors and vehicles slow to adopt.
3. **Overreliance on electric cars:** Electric cars reduce lifecycle emissions but face limitations, including higher production emissions and unsolved issues such as transport inequality and slow uptake.
4. **Aviation:** Decarbonising air travel is constrained by technological barriers for long distances. Electric planes and zero carbon fuels remain unproven at scale, and reducing flight demand, particularly from frequent flyers, faces significant resistance.
5. **Decarbonising shipping:** Maritime shipping, a major future emissions contributor, operates on polluting diesel and faces long asset lifespans. Governance challenges in a global market make regulation difficult, though strategies like green ammonia and slow steaming offer emissions savings.
6. **Cultural attachment to the status quo:** Societal resistance to change, with a sense of entitlement to car use and air travel, hampers decarbonisation efforts. Personal freedoms are often prioritised over collective climate goals. People are generally ready for systemic change but need help and support.
7. **Infrastructure lock-in:** High carbon infrastructure and urban design, oriented toward vehicles not people, lock societies into unsustainable habits.

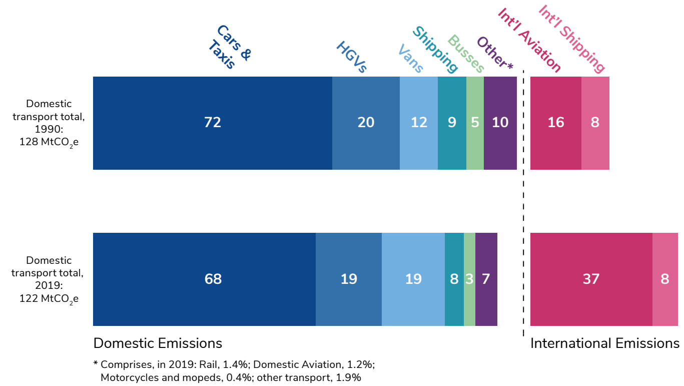


Fig 1: UK domestic transport emissions breakdown by mode in 1990 and 2019, in Anable 2024
(click to enlarge)

Decarbonisation policies

Mainly vehicle and fuel regulation – have been negated by the cumulative impact of a combination of trends, including discrepancies between vehicle test-cycle and real-world performance, the growth in the size and weight of new cars, the slow uptake of battery electric vehicles, the increase in van traffic, minimal progress in efficiency improvements in heavy goods vehicles, and the immense rise in air passenger demand.

Background: 20 Years of UKERC Transport

The guiding principle of the UKERC transport programme was to identify, understand and explore the key issues and challenges to decarbonise transport and mobility in the UK, with an emphasis on using the existing evidence base and analytical capacity that is needed to enable decision-making at national and local levels. Over the past 20 years, UKERC transport research has targeted areas where transport decarbonisation efforts are generating particularly acute technological and governance challenges for the energy system.

Phase 1 (2004-2009)

Build a thorough understanding of the challenges and solutions – can we decarbonise?

Phase 1 laid the groundwork for understanding transport's role in the UK's energy system, focusing on fuel transitions and emerging vehicle technologies (e.g. EVs). It informed the UK government's Low Carbon Transport: A Greener Future strategy (2009), shaping early commitments to cleaner fuels and fostering innovation in low-emission vehicle policies.

Phase 2 (2009-2014)

Develop a portfolio of mitigation actions – how can we decarbonise?

Phase 2 integrated social psychology and behavioural economics into energy modelling to better predict the adoption of low carbon transport modes and technologies. Explored barriers to sustainable transport choices and the role of incentives. Influenced the development of policies such as early iterations of the Plug-In Car Grant scheme by highlighting the importance of consumer acceptance and targeted incentives in achieving decarbonisation goals.

Phase 3 (2014-2019)

How can we accelerate decarbonisation across transport and electricity?

Phase 3 emphasised interactions between transport, urban infrastructure and energy systems, advocating for multimodal solutions and smart integration of transport and land-use planning. Highlighted governance challenges and opportunities. Supported initiatives like the government's Future of Mobility: Urban Strategy (2019), encouraging investment in sustainable urban transport and integrated planning frameworks.

Phase 4 (2019-2024)

What are the challenges and opportunities for deep decarbonisation?

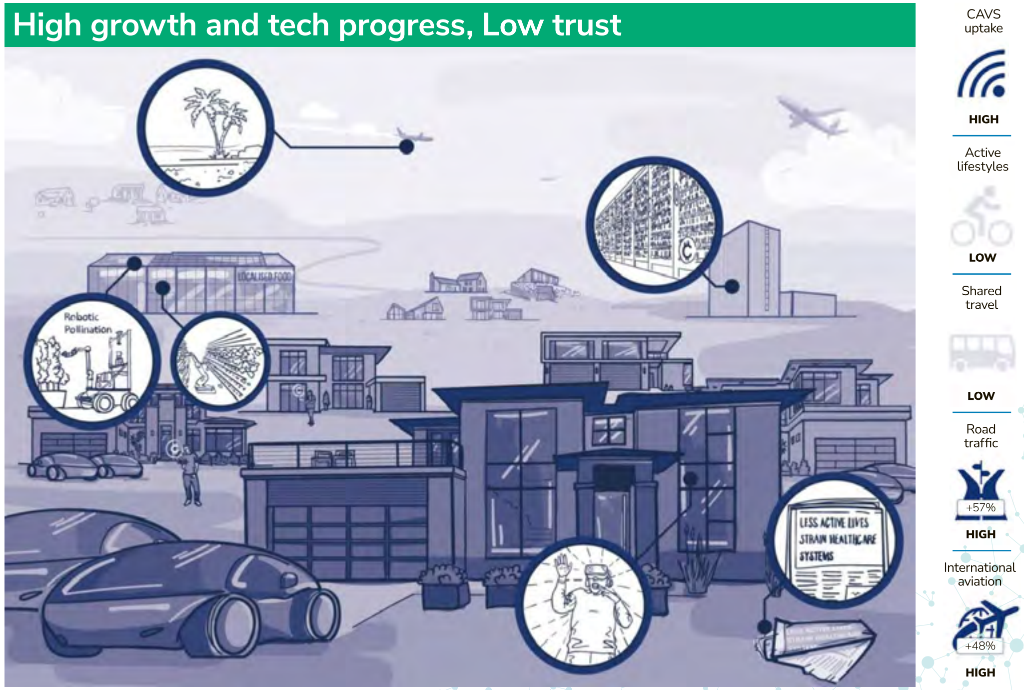
Phase 4 had a dedicated transport theme for the first time. Five projects extended previous systemic energy-transport research to other areas of aviation and shipping, air pollution and health, and planning for EV infrastructure. This highlighted the role of active travel and shared mobility in decarbonisation and contributed to shaping UK policies by providing evidence-based insights that align technical innovation with environmental and social priorities.

Background: UKERC Transport Multi-Disciplinary Approach

The UKERC transport theme adopted a multi-disciplinary approach by integrating technical, social, environmental and economic perspectives to address complex challenges in transport and energy systems. This whole systems approach ensures that transport solutions align with broader energy system goals, address societal needs and support just transitions to a low carbon future. Our work typically takes evidence from engineering, economic, social and psychological research and explores systemic impacts and pathways over time and space. It has informed policies ranging from international climate and health strategies to national decarbonisation frameworks and local air quality actions. In short, the approach combines:

1. **Technical analysis:** Evaluating emerging technologies (e.g., electric vehicles, biofuels) and system-level interactions with energy infrastructure.
2. **Behavioural insights:** Exploring how individual and collective choices affect energy demand and the adoption of sustainable transport modes, services and choices.
3. **Environmental impacts:** Quantifying the benefits of decarbonising transport in terms of emissions reductions and air quality improvements.
4. **Social and equity considerations:** Assessing social change, lifestyles, transport accessibility and their socio-economic impacts, particularly on marginalised groups and in cities.
5. **Policy and governance:** Investigating the implications of governance structures and policy interventions, emphasizing collaboration between stakeholders and cost sharing.

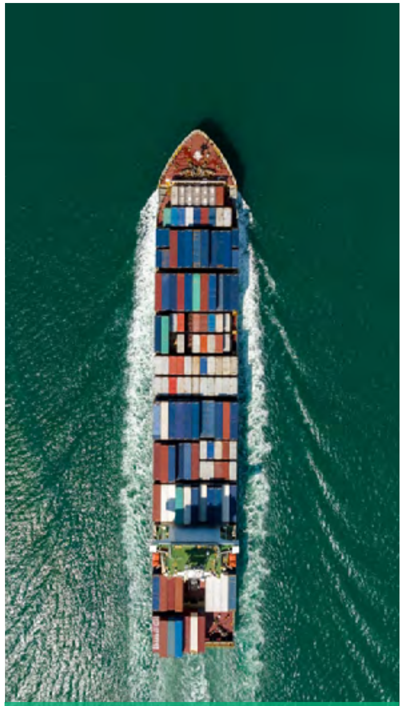
Example: illustration of a plausible societal scenario for the future UK transport system (GO-Science, 2023, with UKERC input)



Summary

This section provides the key messages collated from the UKERC research on transport and mobility, providing links to the detailed pages. The five key topics in UKERC's work on transport — passenger mobility, freight transport, futures and pathways, social and behavioural dimensions and health 'co-benefits' — were chosen to align with the structure and compartmentalisation of the UK government departments responsible for transport, energy and climate change, and health. This structure ensures that UKERC's research provides targeted insights and actionable recommendations that are directly applicable to government priorities, supporting a whole-system approach to transport decarbonisation.

Mobility Summary p8



Freight Summary p10

Futures Summary p11

Social Summary p13

Health Summary p14

Summary – Mobility

Mobility overview

The UK passenger transport sector faces stagnant emissions, growing vehicle size, low EV adoption and rising mobility demand. Solutions include enforcing the ZEV mandate, reducing car mileage by 50% via pricing, regulation and infrastructure, promoting public transport and e-bikes for medium trips and regulating polluting vehicles to meet net zero targets.

p16

Passenger cars

Decarbonising cars requires an integrated approach: scaling EV adoption while addressing systemic barriers, ensuring equitable access and combating counterproductive trends like the popularity of larger, less efficient vehicles. Policies must address vehicle ownership and use, infrastructure and affordability to meet decarbonisation goals.

p17

EV charging infrastructures

Frequent plug-in behaviour by EV owners maximises the financial and carbon-saving potential of V2G systems. Electrified transport can enhance grid flexibility and reduce infrastructure strain when supported by smart demand management and targeted policy interventions at local and national levels.

p18

Planning for EV charging

At-home EV charging regulations are a critical step towards decarbonising passenger transport but require better integration of electricity, housing and transport systems to address affordability, equity and infrastructure planning challenges. Sectoral friction, interdependency and unintended consequences are key issues to tackle.

p21

Public and shared transport

Public and shared transport systems can significantly reduce mobility-related energy demand and carbon emissions, with high socio-economic returns. But their success hinges on targeted investment, effective systemic integration and coordination, supportive measures and prioritisation, and car restraint policies.

p22

Active travel

Active travel provides a highly cost-effective means to improve public health and reduce CO_2 emissions from trips under 10 miles. But effective reductions in car CO_2 emissions happen only when improvements to alternatives are coupled with restrictions to car use with pricing, car restraint and parking restrictions.

p23

Summary – Mobility

Financial incentives

Financial incentives like feebates, purchase taxes and Vehicle Excise Duty can accelerate the transition to ZEVs while discouraging the trend toward larger, resource-intensive vehicles. These policies must be designed to align with broader decarbonisation goals, ensuring they are equitable, revenue-neutral and effective in reducing life cycle emissions.

p24

Pricing of vehicle ownership and use

Effective reductions in car travel happen only when improvements to alternatives are coupled with car restraint. Effective pricing requires careful design to balance behavioural incentives, equity and acceptability. Hypothecation of revenues can amplify the impact of pricing policies by funding sustainable transport initiatives, making them politically and socially viable. Strong leadership and political will be key.

p25

Speed limits

Lower speed limits are among the most cost-effective and immediate measures to cut transport carbon emissions without requiring new technology or infrastructure. Enforced speed limits not only lower emissions but also improve safety, reduce fuel costs and deliver public health benefits by decreasing air and noise pollution.

p26

Air travel

The UK needs to reduce aviation's environmental impacts through technological innovation, demand management and targeted investments. Without significant policy interventions to manage demand, the UK's climate change targets may be unattainable due to the projected growth in aviation emissions.

p27

'Mobesity'

The proliferation of large electric vehicles risks undermining the environmental and economic benefits of the green transport transition. By incentivising smaller, lighter vehicles, regulating the car industry, improving urban planning and addressing the role of advertising, governments can mitigate the negative impacts of larger cars.

p28

Summary – Freight and Logistics Decarbonisation

Freight overview

Freight logistics and decarbonisation.

p30

Urban and last-mile freight

Decarbonising urban freight requires an integrated approach of fleet electrification, demand reduction and operational efficiencies, brought about by congestion pricing and targeted investment in charging infrastructure. Load factor optimisation, e-cargo bikes and urban consolidation centres can cut emissions by up to a third.

p31

Long-distance surface freight

A transformative shift is required, combining efficiency improvements, zero emission technologies and a rebalancing of modal priorities, while addressing economic disparities and maintaining the competitiveness of freight operators.

p32

Green ammonia for shipping

Adoption of green ammonia as an alternative to diesel faces significant barriers, including first-mover risks, safety concerns with regards to toxicity and NO_x/N_2O emissions, and a lack of economic incentives. Infrastructure gaps, slow fleet renewal and competing demand from other sectors exacerbate these challenges.

p33

Summary – Futures and Pathways

Futures overview

Achieving the UK's medium and carbon budgets and net zero by 2050 requires transformative changes in technologies, social practices, infrastructure and institutions in how transport systems are designed, used and powered.

p35

Low energy futures

Transport energy demand reduction supports deeper, faster decarbonisation without relying heavily on high-risk or unproven carbon dioxide removal technologies. It enhances co-benefits such as public health, air quality and reduced resource use. It will require a shift in focus from technological fixes to technological plus systemic, behavioural and structural changes

p36

Net zero societies

Policymakers can use societal scenarios to reflect on a long-term net zero strategy and identify robust policies that perform well across diverse futures, ensuring resilience against uncertainty in societal trends and technological development.

p38

Lifestyle and/or efficiency

To meet Scotland's climate targets, a combined approach of relatively radical lifestyle change and high EV adoption offers earlier reductions, higher cumulative savings and lower system costs. While large-scale infrastructure change is not feasible within the required timescale, delivering within the existing socio-technical system can ease the transition to wider transformation.

p39

Summary – Futures and Pathways

Reducing car use

Achieving necessary deep emissions reductions will require radical and immediate changes, including demand management, restrictions on high-emission vehicles, and a focus on medium- and long-distance car (and air) trips, alongside accelerated electrification and modal shift. Without such measures, the UK will fail to meet its carbon budgets and broader climate commitments.

P40

Car ownership over space and time

Deep neural networks significantly enhance the accuracy of spatially disaggregated car ownership predictions, providing a vital tool for understanding pathways to decarbonising private vehicle fleets and informing transport and energy system planning for net zero goals.

p42

Smart urban mobility

Smart urban mobility technologies, through ICT-driven traffic smoothing and eco-driving, can cut urban transport emissions in the UK by 10 million tCO_2 and avoid £293 million annually in health and environmental costs, but must be carefully managed to avoid rebound effects and integrated with broader electrification and demand management strategies to maximise long-term benefits.

p43

Summary – Social and Behavioural

Social science overview

Policies need to prioritise Avoid and Shift strategies by reducing the need for travel and making sustainable transport modes attractive, accessible and affordable. This requires a coordinated approach that integrates urban design, infrastructure investment, behaviour change and equity-focused policies.

p45

Avoid

Reducing overall travel demand is now essential to meet climate goals. It can deliver faster than technology solutions. Teleworking, trip consolidation, e-commerce and compact, walkable urban design are some of the key strategies for avoiding journeys. Strategies must address systemic and behavioural barriers (e.g., digital inequities, car dependency).

p46

Shift

Evidence shows that policy needs to tackle service quality, accessibility and affordability of non-car modes across all journey lengths and particularly for middle- to long-distance trips for social and leisure purposes. Behavioural and infrastructure interventions must be combined to encourage modal shift.

p47

Improve

Any successful improve strategy involves shifting societal norms, addressing equity concerns and engaging communities in the transition. Combining technological advances with behavioural interventions can maximise benefits, avoid unintended consequences and ensure a just and inclusive transition.

p48

Summary – Health Co-benefits

Health co-benefits overview

Key findings on the air pollution, physical activity and wider economic impacts of transport decarbonisation.

p50

Air quality impacts

Net zero climate policies offer significant health co-benefits by reducing toxic air pollution, particularly through the transition to EVs and reduced vehicle kilometres. PM2.5 pollution remains an issue but is less pronounced than previously thought. Inequalities in exposure to outdoor air pollution remain a challenge, though net zero policies help mitigate them somewhat.

p51

Public health impacts

Net zero pathways deliver profound health benefits across multiple impact pathways, including lower mortality rates, fewer cases of chronic and acute diseases and substantial economic savings, underscoring their critical role in public health and policy-making.

p52

Economic impacts

The cost-benefit analysis strongly supports the urgency of ambitious net zero transport policies. By embedding health and economic co-benefits into policymaking, targeting inequalities, and addressing shortfalls in active travel and indoor air quality, net zero policies can deliver transformative benefits for climate, public health and social equity.

p53

Health economic costs of cars and vans

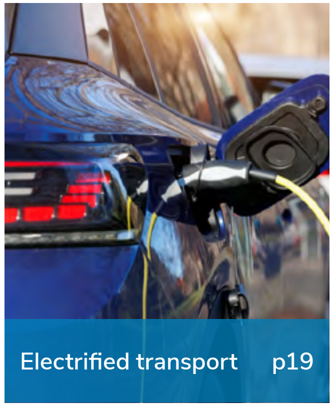
The health costs of air pollution from cars and vans in the UK are substantial, with vehicle emissions burdening the NHS and society by more than £6 billion annually. Nearly 90% of this can be attributed to diesel vehicles, underscoring the urgent need to reduce car and van traffic and to transition from diesel to electric vehicles.

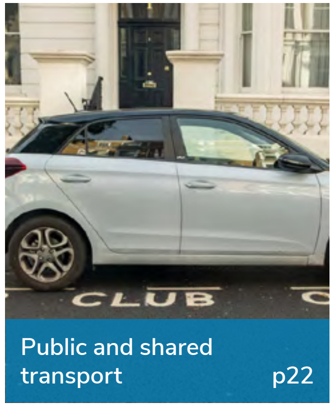
p54

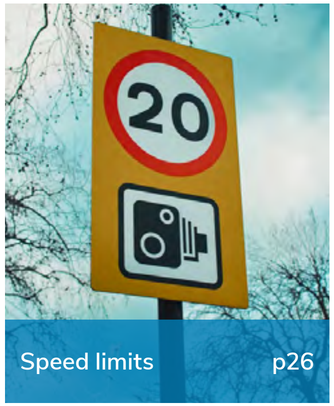
Mobility

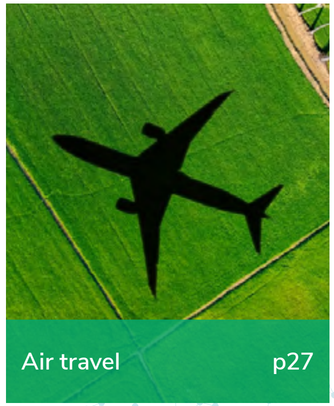
What you will find in this section

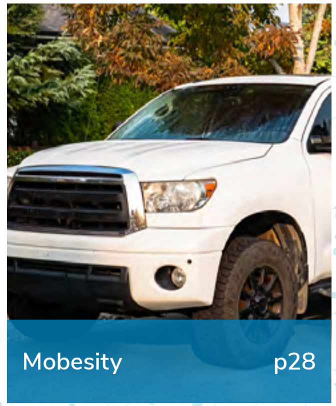
This section highlights the key findings from the UKERC transport research on decarbonising personal mobility – mainly by road and air travel – supporting the policy design process for influencing an increase in uptake of sustainable passenger transport mitigation measures.











Overview

What is the problem?

The UK transport sector, encompassing both air and surface modes, has been a major obstacle to achieving net zero ambitions. Unlike other sectors that have reduced emissions since 1990, total transport emissions have remained stagnant, with 2023 levels almost identical to 1990 levels.

Key contributing factors for the passenger transport sector include the growing size and weight of vehicles, limited uptake of battery electric vehicles and soaring air passenger demand. Compounding this is the expected growth in mobility demand, driven by population and economic growth and structural changes in the economy. This risks offsetting gains from emerging technologies, especially as public transport and active travel modes, such as walking and cycling, remain underutilised due to safety concerns, limited infrastructure and entrenched private car culture.

EV adoption faces equity challenges, with disparities in charging access across rural areas and income groups. Middle- to long-distance air travel is hard to decarbonise because realistic "jet zero" technologies are limited for longer distances.

Policies such as mandatory CO_2 standards for cars and the Renewable Transport Fuels Obligation have had some positive impact but have been negated by these trends. The situation is compounded by inadequate policies, with 70% of required emissions reductions in transport lacking concrete measures. If transport decarbonization fails, the UK's net zero target will be unachievable.

Decarbonising passenger mobility

To address these challenges, significant transformations are needed in vehicle electrification, car usage and modal shift. Here are four key areas:

1. The Zero Emissions Vehicle mandate aims for 100% electric car sales by 2035 but faces hurdles, such as manufacturers requesting more support and rising emissions from heavier vehicles like SUVs. Policies to curb the sales of large, carbon-intensive cars and incentives for smaller, lighter EVs could mitigate these challenges.
2. Regulation (e.g., ZEV mandates or SUV restrictions) provides a clear framework for industry compliance and avoids some equity concerns. Climate Assembly UK found strong public support for restricting the sale of the most polluting cars, with 86% of participants in agreement.
3. Evidence shows that car use must be significantly reduced to achieve emissions targets. Achieving at least a 50% reduction in car mileage by 2030 is critical. Strategies include restricting car use through congestion charges, parking levies, or road closures, coupled with investments in public transport and active travel infrastructure.
4. While most policy efforts focus on short trips, long and medium-distance trips (10–30 km) account for a disproportionate share of emissions. Investment in rapid transit systems (e.g., trams, express buses, and rail) and promoting e-bikes for medium distances can provide viable alternatives. However, these efforts must be paired with measures to discourage car use for longer discretionary journeys.

Passenger Cars: Accelerating the Transition to Zero-emission Cars

20 years of UKERC research has repeatedly shown that systemic, evidence-based policies are critical in accelerating the decarbonisation of cars. The UK needs a more balanced approach combining technological, behavioural and infrastructural solutions to decarbonising cars. While the Zero Emission Vehicle Mandate aims to increase EV adoption, delays in phasing out internal combustion engine vehicles and reliance on plug-in hybrid electric vehicles undermine progress. Some key systemic challenges hinder the proposed transition, including UK industry readiness, infrastructure gaps and charging affordability. Here we look at the transition to zero emission cars in the UK.

Findings

1. Neither the 2035 nor the 2040 ICE phase out target ensures adequate carbon reductions. Full electrification is the most effective route to decarbonisation in the longer term.
2. A 2030 phase-out that includes PHEVs, combined with reduced travel demand and taxing or regulating new inefficient models, can deliver cumulative savings of ~100 $MtCO_2$ by 2050.
3. The trend toward heavier, more powerful vehicles continues to undermine decarbonisation efforts by increasing energy consumption, material demand and lifecycle emissions.
4. The Zero Emissions Vehicle mandate (ZEVM) aims for 100% electric car sales by 2035 but faces hurdles, such as manufacturers requesting more support and rising emissions from heavier vehicles like SUVs.
5. Accompany this with tax or road user charges on the most polluting vehicles: fill revenue gap, avoid rebound, shift modes.
6. The car fleet can be reduced significantly to meet material supply and lifecycle emission constraints. In London, congestion charges, the Ultra Low Emission Zone and improved public transport have contributed to a decline in car ownership and use as well as EV uptake.
7. A reduced car fleet could impact jobs in manufacturing, but these could be 'replaced' with jobs in public transport vehicle manufacturing, shared mobility services or EV infrastructure.
8. The meanings people attach to car ownership – symbolic, emotional and practical – are as important as cost and environmental concerns in shaping attitudes towards EVs.

Phasing out fossil fuel cars

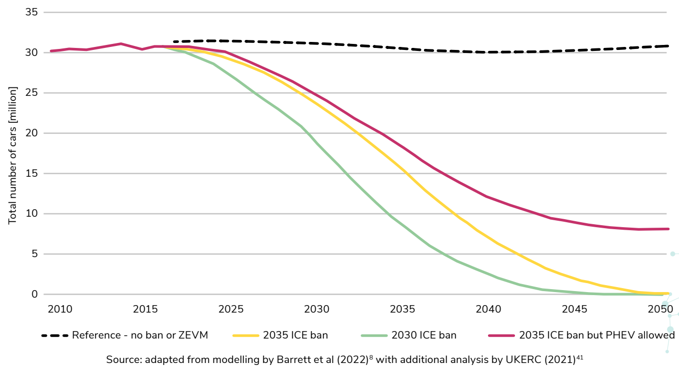


Fig. 2: Modelled projections of ICE cars in the UK - total car stock by phase out dates and type of 'ICE ban' *(click to enlarge)*

Passenger Cars: Accelerating the Transition to Zero-emission Cars

Recommendations

1. Adopt a **phased market transformation** strategy by disincentivising large vehicles (Fig.3), a scrappage scheme benefiting low-income households, introducing stringent efficiency standards, promoting smaller, lighter EVs, VED differentials, road pricing and local access restrictions.
2. Policies to **curb the sales of large, carbon-intensive cars** and **incentives for smaller, lighter EVs** can mitigate the shortcomings of the ZEVM (Fig.4).
3. When assessing the future uptake of EVs we need to account for how 'visible' any charges and upfront incentives are, how often people engage with the detail of the costs, the heterogeneity of elasticities across social groups, whether there are workarounds (cheap tariffs, free electricity at work) and absolute price differentials.
4. Invest in **charging infrastructure and smart grid technologies**, target "charging deserts" and make public charging more affordable (e.g. fairer tax treatment).
5. Timing is critical, as infrastructure readiness and market availability of affordable EVs must align with policy deadlines to avoid socio-economic inequalities.

Key message

Decarbonising cars requires an integrated approach: scaling EV adoption while addressing systemic barriers, ensuring equitable access and combating counterproductive trends like the popularity of larger, less efficient vehicles. Policies must address vehicle ownership and use, infrastructure and affordability to meet decarbonisation goals effectively and inclusively.

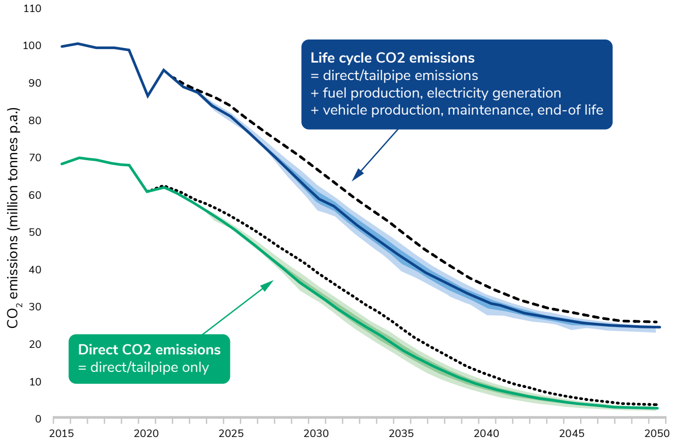


Fig. 3: CO_2 effects of phased car market transformation (UKERC, 2020) *(click to enlarge)*

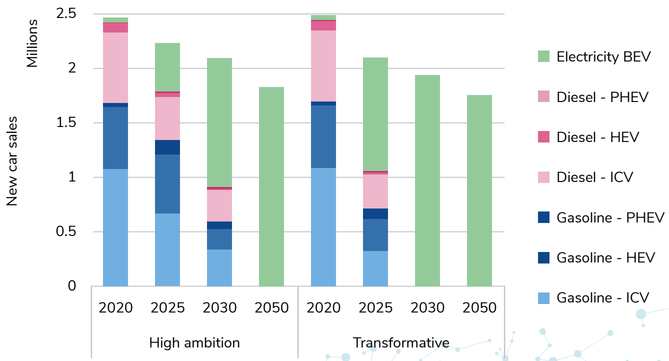


Fig. 4: New car sales by primary fuel and propulsion technology (Brand et al, 2025) *(click to enlarge)*

Electrified Transport: Vehicle-to-Grid (V2G)

As electricity systems integrate increasing shares of variable renewable energy sources like wind and solar, the need for flexible, dispatchable storage solutions is growing. EVs, with their large and distributed battery capacity, offer an untapped potential for grid storage through vehicle-to-grid (V2G) systems. However, realising this potential depends on understanding and optimising the charging and usage behaviours of EV drivers, as well as addressing financial and technical barriers to participation.

Findings

1. Drivers who frequently plug in their EVs benefit from lower charging costs, reducing electricity bills by between **28%** (charge 'when need to') **and 67%** ('whenever') compared to flat tariffs (Fig.5).
2. Frequent plug-ins maximise the availability of EV batteries as dispatchable storage assets for the grid, although this may change with a rapidly increasing EV fleet.
3. V2G charging reduces the carbon intensity of EV charging by **5%** to **6%**, thanks to its alignment with lower-carbon electricity during optimal charging times.
4. The financial benefits and carbon savings provide strong incentives for EV owners to plug in their vehicles whenever possible. Battery degradation costs are offset by the financial gains only when plug-in frequency is maximised.
5. V2G can transform EVs into active participants in the energy transition, reducing emissions and enhancing grid resilience.

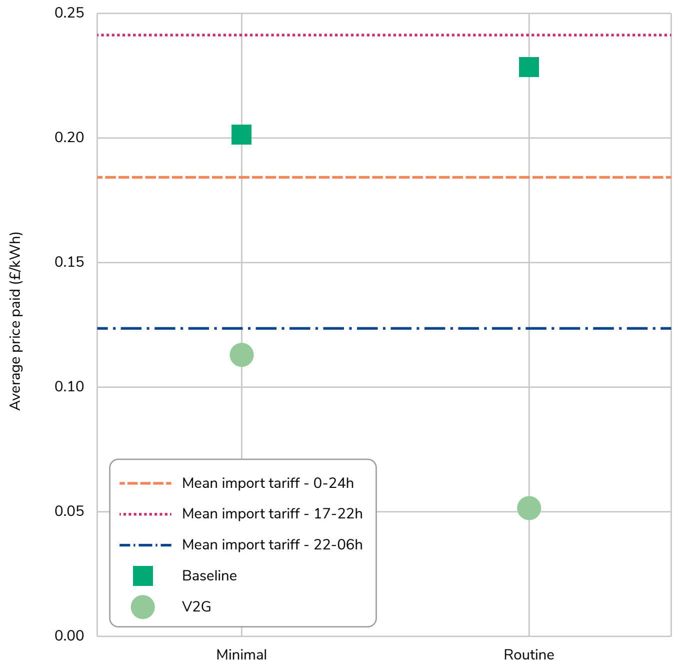


Fig. 5: Comparison of average price paid for baseline (uncontrolled) and V2G-controlled EV charging. Routine: EV always plugged in on arrival. Minimal: only when needed. *(click to enlarge)*

Recommendations

1. Design tariffs and incentives that reward frequent plug-in behaviour, encouraging EV owners to participate in V2G programmes if their vehicle permits.
2. Invest in smart charging systems and load controllers that optimise V2G dispatch based on cost, carbon intensity and grid constraints.
3. Raise awareness about the financial and environmental benefits of frequent plug-ins and V2G participation among EV owners.
4. Develop mechanisms to account for and mitigate battery degradation costs to ensure V2G participation remains financially viable for consumers.

Key message

Frequent plug-in behaviour by EV owners maximises the financial and carbon-saving potential of V2G systems while enhancing grid storage capacity for low-carbon energy systems.

Electrified Transport: Local Power Networks, Flexibility & Energy Demand Reduction

Transport electrification, system flexibility and energy demand reduction are three central strategies for system decarbonisation. Shifting to electric at scale will mean increased generation, transmission and storage capacity, posing strains on local power networks and grid overloading risks unless appropriately planned and invested in. Electrified transport can contribute to system flexibility by:

1. Reducing the need for network upgrades through demand-side management strategies; and
2. Adjusting consumption patterns in response to variable electricity tariffs that reflect broader system requirements.

Findings

1. Energy demand reduction policies can reduce peak transformer loading by 16%, mitigating network strain during high-demand periods and the need for reinforcement of the electricity grid. Smart charging achieves an additional 43% reduction in evening transformer loading. Vehicle-to-grid (V2G) systems, which allow EVs to return power to the grid during peak demand, provide the most significant impact, reducing loading by 69% (Fig.6).
2. Combining demand reduction and flexibility strategies yields the greatest network benefits, optimising energy usage patterns and minimizing reinforcement needs.
3. Widespread reinforcement of the power system will still be necessary in the future, but reduction and deferral is possible.

Recommendations

1. Develop and promote dynamic pricing models (e.g., time-of-use tariffs) at the local and regional level.
2. Provide incentives for installing smart meters, energy management systems and controllable devices.
3. Support battery storage and V2G systems to store surplus renewable energy locally and provide flexibility to the grid during peak periods.
4. Educate consumers about participation in demand reduction reducing bills while supporting the grid's stability.

Key message

Electrified transport can enhance grid flexibility and reduce infrastructure strain when supported by smart demand management and targeted policy interventions at local and national levels.

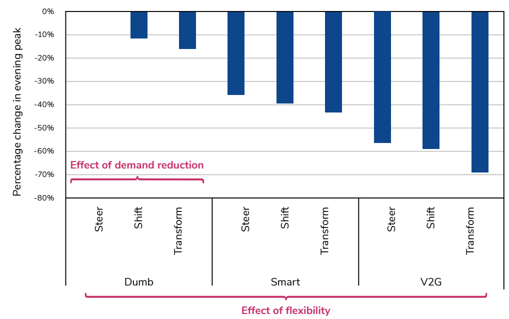
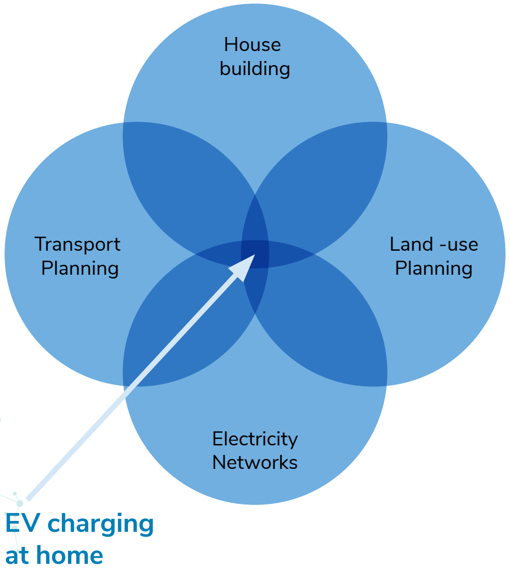


Fig. 6: Changes in evening peak load for dumb, smart and V2G *(click to enlarge)*

Planning for EV Charging at Home

The deployment of at-home EV charging infrastructure in the UK has brought challenges associated with delivering 'Part S' of the Buildings regulations for transport, power, buildings and land-use planning. Social research revealed diverse sectoral and cross-cutting challenges – and some solutions.

Diverse sectoral issues



Category	Findings	Recommendations
Transport	Limited support for shared mobility; risk of overshadowing public/active transport	Prioritise the development of shared charging infrastructure for communal and car club use while integrating EV rollout with active travel and public transport initiatives to reduce car dependency and maximise decarbonisation benefits.
Electricity	Strain on low-voltage networks; high grid upgrade costs	Align grid planning with EV charging needs; fund strategic grid upgrades; ensure equitable access to EV charging through subsidies and investments in underserved areas; promote innovative business models like subscription-based charging.
Buildings	Increased development costs; potential trade-off with affordable housing	Create funding models to balance development costs; avoid trade-offs that hinder affordable housing, e.g. by tailoring policies to balance affordable housing, EV adoption and grid resilience, while addressing regional needs.
Land-Use Planning	Lack of integration across housing, electricity, and transport	Foster cross-sector coordination – the holy grail of land-use planning; integrate land-use planning with EV and grid deployment.
Cross-Cutting Issues	Affordability, equitable access, cost allocation, and need for innovative business models	Encourage equitable cost-sharing across government and industry; support underserved areas; promote innovation in charging solutions; establish governance mechanisms to coordinate across sectors.

Key message

At-home EV charging regulations are a critical step towards decarbonising passenger transport but require better integration of electricity, housing and transport systems to address affordability, equity and infrastructure planning challenges. Sectoral friction, interdependency and unintended consequences are key issues to solve.

Public and Shared Transport

Public transport has a lower carbon intensity per passenger-km compared to private cars, even in diesel-dominated fleets. Shared mobility models, such as car clubs, peer-to-peer car sharing and ride-sharing, reduce overall vehicle ownership and mileage, leading to substantial energy savings. But the lack of integration across transport modes reduces the effectiveness of public transport systems. Car dependency and perceived inconvenience remain significant challenges for modal shifts. A mix of both electric (urban, intercity) and hydrogen (rural, underserved) powered trains will be required to meet growing passenger demand.

Findings

1. **Investments in high quality public and shared transport** systems can contribute to a 20%-30% reduction in emissions in urban areas under high-uptake scenarios.
2. **Public transport investment** is more effective when combined with congestion charges or parking restrictions.
3. **Car clubs** decouple car use from ownership, reducing overall vehicle mileage among members. Members also adopt alternative modes like walking and cycling more frequently.
4. **Shared transport schemes** reduce capital costs for users and improve vehicle utilisation rates, with emissions reductions of up to 15% in urban areas.
5. **Travel planning** can reduce car usage by 6-30%, primarily shifting travel to public transport or active travel.

National level policies

1. Expand **electric bus, rail and H2 rail** networks with a focus on renewable-powered charging infrastructure and H2 rail in non-electrified areas.
2. Implement **congestion pricing and low-emission zones** to discourage car use while reinvesting revenues into public transport improvements.
3. Promote the **benefits of public and shared transport**, emphasising cost savings, environmental benefits and health co-benefits.

Local level policies

1. **Increase funding** for fully electric bus systems, urban rail systems, shared mobility hubs, especially in underserved urban and suburban areas.
2. **Develop multimodal transport networks** linking public transport with walking, cycling, micromobility and shared mobility options.
3. Urban planning should **prioritise the reallocation of road space** from private vehicles to space efficient public transport and active travel modes.

Key message

Public and shared transport systems can significantly reduce mobility-related energy demand and carbon emissions, with high socio-economic returns. But their success hinges on targeted investment, effective systemic integration and coordination, supportive measures and prioritisation, and car restraint policies.

Cross-cutting actions

1. Real-time journey planning and integrated ticketing across modes.
2. Develop demand-responsive transport solutions in ‘hard to reach’ areas.

Active Travel: Impact on Life-cycle CO_2 Emissions

We know that lifecycle CO_2 emissions from cycling can be more than 30 times lower for each trip than driving a fossil fuel car, and about 10 times lower than driving an electric one. But car-centric culture and infrastructure pose significant challenges to encouraging modal shift. Cycling and walking infrastructure in the UK is often poorly connected and unsafe, particularly in suburban and rural areas. Inconsistent funding and lack of prioritisation further hinder the shift.

Findings

1. Active travel can significantly reduce mobility-related CO_2 emissions, but without car restraint measures (e.g., road pricing, congestion charges), the full potential of active travel cannot be realised.
2. Empirical evidence showed that people in cities who cycled daily had an 84% lower carbon footprint than those who did not.
3. People who shifted from car to bike for just one day a week cut their carbon footprint by 3.2kg of CO_2 (Fig.7) – equal to the CO_2 from sending 800 emails.
4. Active travel can realistically substitute for 41% of short car trips, saving 5% of CO2e emissions from car travel.

Recommendations

1. Increase funding for active travel infrastructure to Dutch levels of >£20 per capita annually.
2. Focus on high-quality, segregated cycling and walking infrastructure, prioritising urban and inter-urban areas.
3. Embed active travel at the core of urban planning policies that focus on accessibility by public and active transport.
4. Implement policies to reduce car dominance such as road pricing, parking availability and road space reallocation.

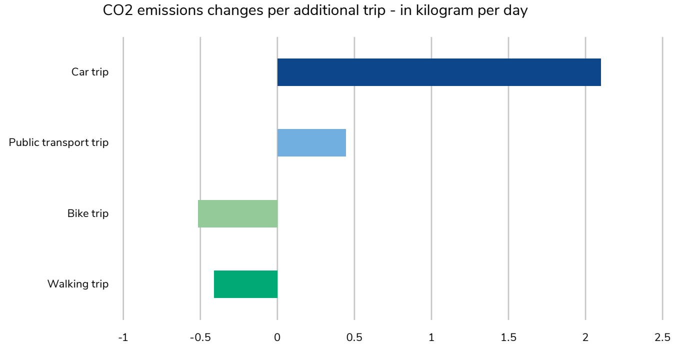


Fig. 7: Changes in emissions per additional trip ($kgCO_2$/day)
(click to enlarge)

Key message

Active travel provides a highly cost-effective means to improve public health and reduce CO_2 emissions from trips under 10 miles. But effective reductions in car CO_2 emissions happen only when improvements to alternatives are coupled with restrictions to car use with pricing, road closures and parking restrictions.

Highlights:

1. Shifting just one daily car trip to active travel cuts individual carbon footprints by about 0.5 tonnes of CO_2 annually. This is comparable to the emissions from a transatlantic flight.
2. If adopted widely, this could reduce emissions from urban car travel by up to 8% across Europe.

Financial Incentives to Accelerate the Low Carbon Mobility Transition

Financial incentives are essential for reducing transport energy demand and accelerating the transition to zero-emission vehicles. They shape consumer choices, encouraging low carbon technologies and sustainable mobility. However, poorly designed incentives can lead to unintended outcomes, such as promoting larger, less efficient vehicles such as large e-SUVs. Financial incentives are a core element of market transformation approaches – flexible CO_2 grading with tighter limits over time ensures sustained decarbonisation while providing clarity to manufacturers and consumers.

Policy instrument	Findings	Challenges and considerations	Recommendations
Feebates	Highly effective in reducing tailpipe and life cycle emissions. Effective at accelerating low carbon technology adoption.	Strong upfront price signals based on CO_2 emissions levels are effective. But design complexity; requires balancing rebates and surcharges on an annual basis.	Use CO2-graded feebates for strong price signals; ensure revenue neutrality by design; tighten CO_2 bands over time; curb vehicle mass, size and energy demand.
Purchase Taxes	Accelerates EV uptake and reduces energy demand and emissions. Phasing out the most polluting vehicles now could save 97 million tCO_2 by 2050, equivalent to around 1.6 years' worth of current UK car CO_2 emissions.	Strong upfront price signals based on CO_2 emissions levels are effective. Hypothecation of revenues is key to overcome public resistance to higher upfront costs.	Introduce subsidies for low carbon vehicles and penalise high carbon purchases with CO2-graded taxes; introduce tiered incentives that link subsidies to vehicle size, weight and emissions, with higher rebates for smaller, energy-efficient vehicles (incl. e-bikes, e-cargo bikes).
Vehicle Excise Duties	Moderate impact; generates steady revenue streams.	Unpopular among drivers; regressive impact on low-income households.	Apply graduated VED; use revenues to support public transport and EV infrastructure investments.
Scrappage Schemes	Minimal life cycle benefits; may increase emissions.	Embodied carbon in new vehicles offsets scrappage gains.	Avoid large-scale scrappage schemes unless paired with strong recycling and reuse strategies.

Key message

Financial incentives like feebates, purchase taxes and VED can accelerate the transition to ZEVs while discouraging the trend toward larger, resource-intensive vehicles. These policies must be designed to align with broader decarbonisation goals, ensuring they are equitable, revenue-neutral and effective in reducing life cycle emissions.

Pricing of Vehicle Ownership and Use

Pricing mechanisms like congestion charges, road pricing and fuel taxes are critical tools for managing travel demand, reducing emissions and raising revenue for sustainable transport.

Findings

1. Congestion charging can be very effective at reducing vehicle trips, congestion and emissions, e.g. in London and Stockholm.
2. Road pricing in cities has potential for broader geographic application beyond city centres, addressing congestion on intercity corridors. Dynamic pricing showed promise for reducing traffic and emissions. Revenue neutrality is critical, with hypothecated funds invested in sustainable mobility options.
3. National road pricing schemes could reduce emissions by 10-15% if charges are sufficiently high to deter unnecessary car trips.
4. Equity concerns can be addressed by redistributing revenues to invest in affordable, high-quality public transport systems, promote active travel, providing rebates for low-income households or invest in EV charging infrastructure in underserved areas.
5. Policymakers may need to phase in new pricing mechanisms like per-mile road pricing to address long-term fiscal gaps from electrification.

Recommendations

1. Implement national road pricing: e.g. introduce a pay-per-mile system with dynamic pricing based on location and time of day.
2. Expand congestion charges to regional hubs: e.g. scale congestion pricing models beyond major cities to regional centers.
3. Hypothecate pricing revenues: e.g. direct funds toward active travel, public transport and shared mobility, particularly in underserved areas.
4. Mitigate equity concerns, e.g. provide targeted rebates, exemptions or subsidies to low income and rural households.
5. Enhance public acceptability, e.g. consult on and communicate the benefits of pricing policies and low emission zones.

Key message

Effective reductions in car travel happen only when improvements to alternatives are coupled with car restraint and redesign of the built environment for people, not cars. Effective pricing requires careful design to balance behavioural incentives, equity and acceptability. Hypothecation of revenues can amplify the impact of pricing policies by funding sustainable transport initiatives, making them politically and socially viable. Strong leadership and political will are key.

Speed Limits and Their Cost-effective Enforcement

Optimising – often lowering – speed limits and enforcing them cost-effectively have the potential to reduce carbon emissions particularly for road, maritime and air transport while simultaneously offering multiple co-benefits such as reduced transport costs and congestion, improved air quality and safety, and quieter environments.

Findings

1. For roads, lowering speed limits on motorways can cut CO_2 emissions by 8-10% for cars and vans, about 2 million tonnes annually in the UK.
2. Electric vehicles, SUVs and HGVs may see larger gains due to the exponential relationship between speed, drag and fuel consumption.
3. Enforcing urban speed limits reduces stop-start driving, cutting fuel use by 5-15% in cities.
4. Cost-effective enforcement through automated speed cameras or intelligent speed assistance can ensure compliance with minimal overheads.
5. For air travel, reduced cruising speeds for long-haul flights, combined with improved flight routing and reduced holding patterns, can save up to 8-10% in fuel consumption and non-CO_2 climate impacts at acceptable time penalties (10-15 mins).
6. For shipping, slowing down container ships (“slow steaming”) has been shown to reduce fuel use and CO_2 emissions by up to 30%. Extended delivery times can challenge supply chains, though improved planning mitigates this impact.
7. Wider impacts: Speed limits could reduce traffic growth by making travel times more predictable and reducing the incentive for high-speed driving. They could also influence vehicle design, potentially leading to cars that are more energy-efficient – potentially helping to reverse the ‘mobesity’ trend.

Recommendations

1. Expand variable, max. 60mph, speed limits within smart motorway schemes.
2. Mandate insurance premium discounts for compliant drivers (e.g., usage-based insurance).
3. Follow historical precedent that demonstrates that such measures can be adopted effectively, even in car-dependent societies.
4. Work closely with airlines and shipping operators to minimise impacts on operational efficiency.

Key message

Lower speed limits is among the most cost-effective and immediate measures to cut transport carbon emissions without requiring new technology or infrastructure. Enforced speed limits not only lower emissions but also improve safety, reduce fuel costs and deliver public health benefits by decreasing air and noise pollution.

Air Travel

The UK faces significant challenges in aligning aviation growth with its climate goals. Aviation emissions have risen sharply and are projected to dominate residual emissions in 2050. This growth disproportionately benefits higher-income groups, as frequent leisure travel drives demand, while lower-income households rarely fly. Aviation's climate impact is underestimated, as forecasts often exclude non-CO_2 effects, and its tax advantages create an economic imbalance, contributing to £billion tourism deficit.

Findings

1. Aviation has a disproportionate impact on emissions. An average resident in England flies only 2.9 times a year (0.4% of all trips) yet flying contributes 44% of passenger miles and 55% of CO2e emissions (Fig.8).
2. Despite technological improvements, both CO_2 and non-CO_2 emissions from aviation could significantly impact the remaining UK's carbon budget in 2050.
3. Aviation primarily benefits higher-income individuals, with the wealthiest flying most frequently. Air travel remains largely inaccessible to lower-income groups.
4. Public opinion supports policies that limit air travel growth, particularly frequent flying.
5. While aviation has economic benefits, incl. employment and tourism revenue, the tourism deficit suggests that domestic spending could compensate if air travel were reduced.

Recommendations

1. Include international aviation emissions and high-altitude effects in carbon accounting for passenger travel.
2. Introduce targeted measures to reduce the frequency of leisure and social flights, raise public revenue and discourage excessive flying, particularly among wealthier individuals, such as taxation or frequent flyer levies. Champion virtual meeting solutions.
3. Develop an integrated net zero aviation strategy that balances demand and technology, which should focus on establishing clear phase-out targets for fossil-fuel-based aviation fuels, accelerating investment in sustainable aviation fuel and electric technologies for short-haul flights, no expansion of airport capacity, implementing fiscal measures and improving public understanding of aviation's climate and equity impacts.

Key message

The UK needs to reduce aviation's environmental impacts through technological innovation, demand management and targeted investments. Without significant policy interventions to manage demand, the UK's climate change targets may be unattainable due to the projected growth in aviation emissions.

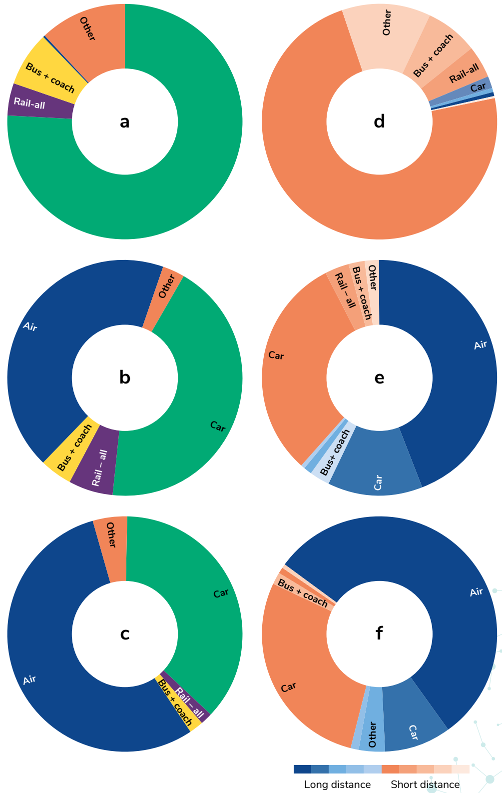


Fig. 8: Shares of trips, miles and CO_2e emissions per capita by mode (Wadud et al 2024) *(click to enlarge)*

Mobesity

EV sales figures indicate a remarkable transformation in the global vehicle fleet, with 14% of new cars sold being electric. However, this shift is paradoxically intertwined with an increase in the production, sales and use of large and heavy vehicles, a phenomenon we coined 'mobesity'. While electrification remains vital, addressing the cultural and economic drivers of SUV popularity is equally critical. Without robust interventions, SUVs could undermine the UK's efforts to meet climate commitments, emphasising the need for cohesive policies that balance technology, behaviour and fiscal instruments.

Ratio of sales of SUV to Battery Electric Vehicles in 2023
3:1

Findings

1. **Vehicle size matters:** While more efficient than internal combustion engine vehicles, large EVs consume more energy than smaller EVs, diminishing their overall carbon reduction potential. This also means higher prices, higher lifecycle emissions, and potentially amplifies the geopolitical tensions, risk and strategic uncertainty that mining for batteries is inducing.
2. **Carbon lock-in:** between 2015 and 2019, SUVs outsold BEVs at a 37:1 ratio, adding about 8 million tCO_2 in cumulative emissions. In 2023 the ratio was still 3:1.
3. **Particulate emissions:** Heavier vehicles cause greater tyre and road wear, emitting more PM2.5 harmful to public health.
4. **Artificial scarcity:** Automakers prioritise large EVs due to higher profit margins while reducing the availability of smaller models. Aggressive marketing also fuels demand for larger EVs, which constitute 35% of global EV sales.

Recommendations

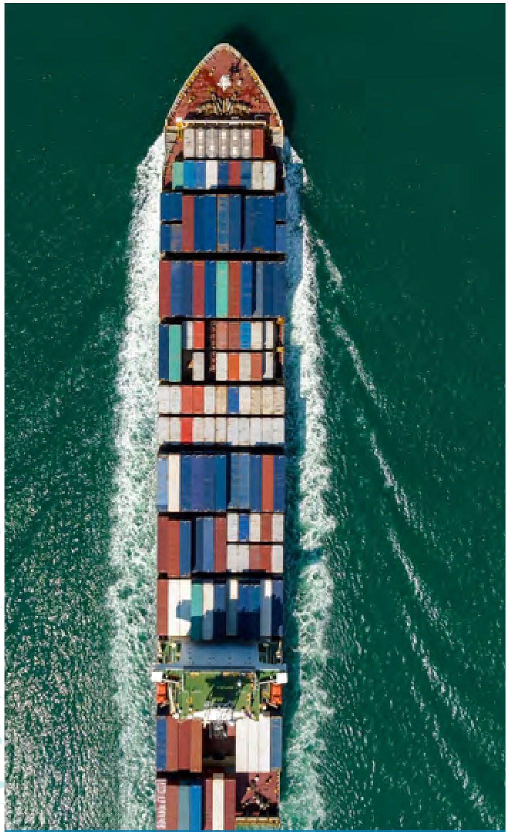
1. Tighten emissions regulations and align UK with EU vehicle standards to prevent regulatory backsliding.
2. Introduce weight-, size-, or power-based **taxation** and CO_2 – emission graded taxes to incentivise smaller, more efficient EVs.
3. **Stronger incentives** for manufacturers to sell smaller EVs.
4. **Adjust subsidies and incentives** to favour smaller, efficient models, shifting market offerings and consumer preferences.
5. **Reform vehicle financing** and Personal Contract Purchase deals to running costs and incorporate stronger emissions-based penalties.
6. **Support advancements in battery technology** to increase energy density and reduce material use.
7. Support R&D in reducing toxic emissions from **tyre wear.**
8. Local governments to **redesign urban spaces** to discourage or ban large vehicle use and promote and invest in PT and active travel.
9. **Ban advertising** for large EVs and **educate consumers** on the environmental and economic impacts of large EVs (similar to smoking health warnings) and the benefits of smaller models.

Key message

The proliferation of large electric vehicles risks undermining the environmental and economic benefits of the green transport transition. By incentivising smaller, lighter vehicles, regulating the car industry, improving urban planning, and addressing the role of advertising, governments can mitigate the negative impacts of larger cars.

Freight

This section highlights the key findings from the UKERC transport research on decarbonising urban and long-distance freight, supporting the policy design process for influencing an increase in uptake of sustainable freight transport modes and services.



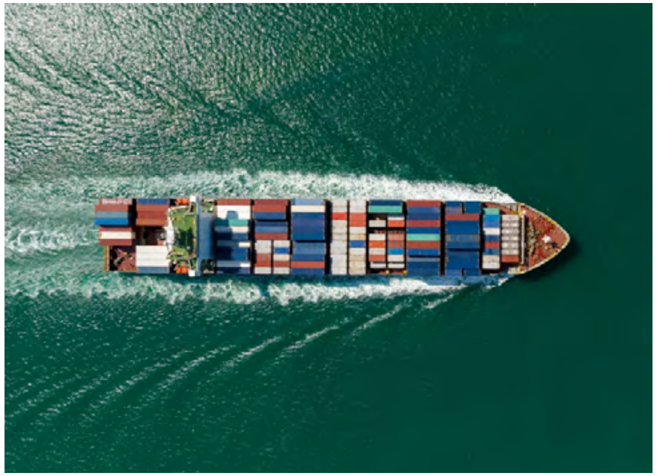
Freight Overview

What is the problem?

1. Collectively, the road, rail and maritime freight transport sectors represent nearly 7% of UK CO_2 emissions and continue to rise fuelled by e-commerce demand.
2. Freight transport is one of the fastest growing contributors to greenhouse gas emissions, with over 98% of freight road transport energy still reliant on fossil fuels.
3. Decarbonising long-distance freight to meet net zero targets is a major challenge due to high energy demands over long distances, heavy reliance on diesel-fuelled HGVs, a fragmented sector with cost and time-driven priorities and limited adoption of zero-emission technologies due to infrastructure and cost constraints.
4. Freight in urban areas is challenged by rapid growth of e-commerce demand, traffic congestion, air pollution regulations and inefficiencies in delivery routes and vehicle usage.
5. Compounding this is the expected growth in freight transport demand, driven by structural changes in the economy and population and economic growth. This risks offsetting gains from emerging technologies, especially as shared freight services, such as consolidation centres, and last-mile delivery modes, such as e-cargo bikes, remain underutilised due to relatively cheap diesel fuel and a road freight industry used to the flexibility and convenience the road brings, despite increasing congestion costs.
6. Middle- to long-distance freight is hard-to-abate because realistic zero emission technologies are limited for longer distances.

Potential solutions

1. Electrification is a common need across all freight modes and therefore is a no-regrets, low-risk investment from both public and private investors.
2. Renewable Fuels of Non-Biological Origin e.g. hydrogen-derived fuels such as methanol and ammonia, may also be important in some niches for road and rail freight, but have the greatest role in decarbonising domestic and international maritime freight.
3. There is some evidence that UK ports can be key nodes in the UK freight sector's decarbonisation. They are both interfaces between the modes (road, rail and shipping), but also represent locations where infrastructure and decarbonisation solution synergies are most likely exploited. They are also likely to be hubs for wider offtake of electrification and renewable fuel obligations, for example for decarbonising co-located industries.



Urban and Last-mile Logistics

Vans accounted for 16% of UK domestic transport CO_2 emissions in 2019, up from 9% in 1990. The sector is dominated by diesel-powered vans and trucks, which contribute significantly to urban air pollution and congestion. Van traffic is forecast to grow by up to 25% by 2030 because of changing demand for e-commerce and rapid delivery services, expanding urban populations, urban deindustrialisation, increasing demand for outsourced servicing functions, and logistics sprawl resulting in longer journeys.

Findings

1. **Transition to ZEVs:** The phase-out targets for new vans (70% ZEVs by 2030, 100% by 2035) are insufficient to meet medium-term carbon budgets. While electric vans are expected to dominate urban freight, challenges remain due to limited battery range, long charge times and operational constraints that can hinder fleet economics.
2. **Systemic shifts:** Average van load factors remain low, with many vans operating below 50% capacity. Optimising load factors and avoiding van trips through shared logistics, urban consolidation centres and using digital tools to optimise deliveries could reduce emissions by 10-30% in urban areas. E-cargo bikes and micro-electric vehicles could reduce van mileage by ~15% in high-density city centres.
3. **Key market barriers** include fragmented supply chains with limited collaboration between operators, high upfront costs of zero-emission vehicles and insufficient charging infrastructure. The patchiness of charging facilities, particularly for heavy-use fleets, remains a critical challenge for widespread electrification.

Recommendations

1. **Fleet electrification:** Accelerate adoption through stricter phase-out timelines and financial incentives for e-vans.
2. **Invest in infrastructure:** Develop fast-charging hubs for urban freight fleets and ensure equitable access to charging networks across cities.
3. **Address market barriers:** Encourage fleet sharing and collaborative logistics, subsidise the upfront cost of ZEVs and provide targeted support for SMEs.
4. **Demand management:** Introduce urban congestion pricing or emissions-based road pricing for freight vehicles to discourage unnecessary trips and optimise route planning. Incentivise slower delivery times (e.g., next-day rather than same-day) to allow for more consolidated deliveries.
5. **Foster collaboration** between urban freight consolidation, logistics operators through shared data platforms and route optimisation tools to maximise vehicle utilisation and reduce empty miles.
6. **Raise awareness** of the environmental and social impacts of urban freight, encouraging consumers to adopt sustainable delivery choices, such as delivery lockers or slower delivery options.

Key message

Decarbonising urban logistics requires an integrated approach of fleet electrification, demand reduction and operational efficiencies. Combining load factor optimisation, e-cargo bikes and urban consolidation centres can cut emissions by up to a third. Policies such as congestion pricing, targeted investment in charging infrastructure and incentives for collaborative logistics are essential to support this systemic change.

Long-distance Surface Freight

Decarbonising long-distance freight is a complex challenge for achieving net zero emissions, given the sector's fast growth, fragmentation, intense cost and time pressures and reliance on fossil fuels. There is no single "silver bullet" policy, as the sector's challenges require a mix of technical and demand solutions tailored to specific contexts, modes and types of cargo.

Findings

1. Transition to ZEV: The phase-out targets for new non-zero-emission HGVs of 2035 (<26t) and 2040 (all) will not be enough to decarbonise the sector by 2050.
2. Is the future electric? Fully electric HGVs could dominate in urban and regional freight with investment in fast-charging hubs but still have major structural limitations – especially related to battery range and charge time, making it difficult for truck owners to operate trucks economically.
3. Need for accelerated technological innovation and targeted investment in electrification for shorter routes and hydrogen fuel cells or biofuels for longer, heavy-duty routes. High costs and fuel infrastructure gaps remain as surmountable barriers.
4. Railfreightremainsmoreenvironmentally friendly than road freight, but potential for emissions reductions are diminished by reliance on 'dirty diesel'.
5. Load factor optimisation: Improving load factors can reduce fuel use by 10-20%, while also cutting costs for operators. Collaborative logistics, digital freight platforms, and incentives to reduce empty running are essential and need to be developed and supported.
6. Market barriers: Stakeholders have emphasised the importance of aligning taxation, subsidies and regulations to encourage private-sector uptake of zero-emission technologies.

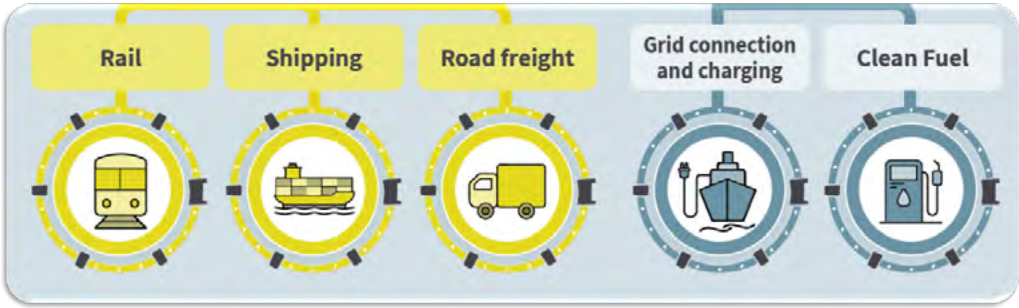


Fig. 9: The main strategic priorities for surface freight decarbonisation *(click to enlarge)*

Recommendations

1. Set clear, ambitious targets, including the 2040 phase out date for fossil fuel freight vehicles, supported by effective policies.
2. Act on evidence on electrification, including rail freight electrification, shore power in ports and charging infrastructure for HGVs.
3. Develop and deploy a whole freight system, whole UK analysis capability.

Key message

A transformative shift is required, combining efficiency improvements, zero-emission technologies and a rebalancing of modal priorities (Fig.9), while addressing economic disparities and maintaining the competitiveness of freight operators. Policies must deliver systemic coordination, foster innovation and provide targeted support to ensure the sector transitions equitably and effectively without compromising its critical role in the economy.

Green Ammonia for Shipping: Opportunities and Challenges Across the Fuel Supply Chain

The International Maritime Organisation's revised 2023 targets heighten urgency for shipping organisations to cut energy consumption and transition away from fossil fuels. Green ammonia, produced from renewable hydrogen and emitting no direct CO_2 during combustion, is a prominent alternative fuel option under consideration. This 'zero carbon' fuel could decarbonise 60% of global shipping when offered at just 10 regional fuel ports. Here we summarise stakeholder research on key opportunities and challenges.

Findings

Systemic transition challenges:

- Significant developments are required across the supply chain, encompassing onboard and portside infrastructure, incentives for fleet retrofitting, policies to de-risk early adoption, and mitigation of safety concerns and environmental impacts.
- Competing demand for green ammonia from other sectors and limited deployment of supply-side infrastructure impede progress, exacerbating time pressures to meet climate goals.

Importance of immediate action:

- While the exploratory phase of alternative fuels fosters innovation, it risks delaying near-term decarbonisation. Rising costs of new fuel infrastructure will compound this issue as timelines shrink.
- Parallel measures to reduce liquid fuel dependence – such as slow steaming, wind propulsion and ship efficiency improvements – are critical to achieving IMO's 2030/40 targets.

Recommendations

1. **Accelerate adoption of green ammonia technologies:** Invest in scalable green ammonia infrastructure, incentivise retrofits and new builds with dual-fuel engines, and mitigate first-mover risks through subsidies or tax benefits.
2. **Enhance efficiency and collaboration:** Promote slow steaming, operational retrofits, and cross-sectoral partnerships to balance resource allocation, share knowledge, and validate the environmental feasibility of green ammonia.
3. **Align policies and standards:** Develop clear, coordinated international policies addressing economic, environmental, and safety aspects, ensuring alignment with global climate targets and consistent safety standards.

Key message

Green ammonia, a promising alternative maritime fuel, offers storage advantages over hydrogen, established handling expertise and zero direct CO_2 emissions when combusted. However, adoption faces significant barriers, including first-mover risks, safety concerns with regards to toxicity and NO_x/N_2O emissions, and a lack of economic incentives. Infrastructure gaps, slow fleet renewal and competing demand from other sectors exacerbate these challenges.

Futures: Pathways to Net Zero, Clean Air and Better Health

This section highlights critical insights from the UKERC transport research on how systems modelling combined with narrative based, socio-technical scenarios have been used to inform future pathways to decarbonising transport.


Futures overview p35


Low energy demand futures p36

Net zero societies p38


Lifestyle and efficiency: Scotland p39


Reducing car use p40


Car ownership over space & time p42


Smart urban mobility p43

Futures Overview

What is the problem?

The rationale for the scenarios and futures work stems from the urgent need to address three major challenges:

1. Current trajectories are inconsistent with net zero goals, requiring a step-change in emission reductions by mid-century. It will be impossible for the UK to meet the decarbonisation targets in 2035 and 2050 without focusing on the amount of movement of people and goods.
2. Increasing travel demand, driven by population growth and the future of work, retail and leisure, threatens to outpace emissions savings from technological improvements.
3. An electric future will take some time. Decarbonisation strategies must avoid widening mobility inequalities, ensuring solutions are inclusive and just for all demographics and regions.

By modelling possible futures and stress-testing a range of interventions, policies and strategies, the UKERC pathways work identifies practical, evidence-based strategies to accelerate decarbonisation. It focuses on reducing energy demand, shifting to low carbon modes and improving vehicle and fuel efficiency while addressing the wider co-benefits of decarbonisation, such as better air quality, health outcomes and quality of life.

What are the potential solutions

1. Achieving the UK's medium and carbon budgets and net zero by 2050 requires transformative changes in technologies, social practices, infrastructure and institutions in how transport systems are designed, used and powered. This involves both higher uptake of lower and zero carbon vehicles combined with efficiency gains, mode shifts and significant alterations to work, leisure and shopping travel patterns.
2. Climate action often – but not always – goes hand in hand with improvements in air quality and public health.
3. Scenarios can explore "what if?" questions, such as how technological and positive social change can accelerate zero emission technology uptake and use, or the effects of reducing travel demand at scale within exogenous social and geo-political settings. Scenario narratives and storylines can provide input into systems modelling to quantify systemic effects.
4. Transitions will differ across urban, suburban and rural areas. Urban regions are primed for modal shifts (e.g., e-biking, electrified public and shared transport), while rural areas face unique challenges in reducing car dependency due to limited infrastructure and services. Equity is central – solutions must prioritise underserved communities by improving accessibility, affordability and fairness in policy design.

Low Energy Demand Futures

Transport energy demand reduction may have a critical role in achieving climate change mitigation targets, improving public health and reducing total energy requirements, particularly in the short term. Using a whole-systems scenario modelling approach, we illustrate pathways to sustainable and equitable transport futures and highlight the scale and pace of action required.

Findings 1: A novel methodology

1. By bringing together diverse expertise and perspectives, our multi-sector, multi-disciplinary, whole systems approach (Fig.10) identifies synergies, trade-offs and unintended consequences that might be overlooked in siloed studies. For example, it ensures that behavioural, technological and policy innovations are assessed within real-world constraints and contexts.
2. This comprehensive methodology creates robust evidence, fosters cross-sector collaboration and enhances policy relevance, ensuring that pathways to net zero are resilient, equitable and effective.
3. The framework provides a template that can assess the relative contribution of a vast range of interventions on energy demand reductions to meet emission targets. It is the use of detailed sectorial models with a systems-integration model, tied together by a rich scenario narrative recognising sectoral inter-linkage that is replicable.

Key message

A multi-sector, multi-disciplinary, whole systems approach is essential for decarbonisation, as it identifies synergies, trade-offs and real-world constraints across sectors and disciplines, ensuring robust, equitable and effective pathways to net zero.

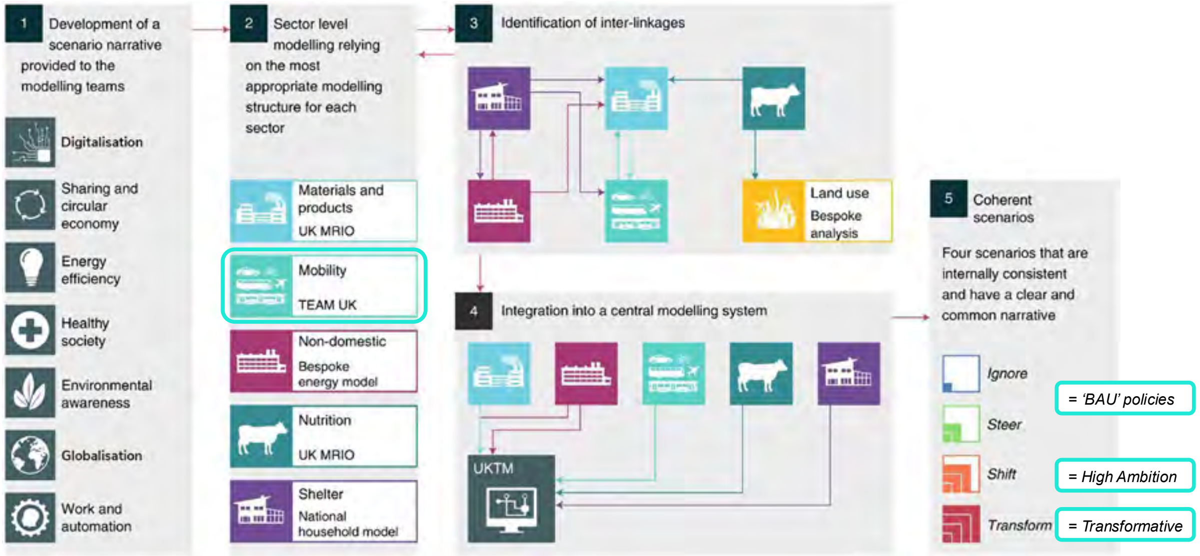


Fig. 10: A multi-sector, multi-disciplinary, whole systems approach to model low energy futures *(click to enlarge)*

Low Energy Demand Futures

Transport energy demand reduction may have a critical role in achieving climate change mitigation targets, improving public health and reducing total energy requirements, particularly in the short term. Using a whole-systems scenario modelling approach, we illustrate pathways to sustainable and equitable transport futures.

Findings 2: Results

1. A reduction of up to 68% in transport energy demand by 2050 is achievable compared to baseline levels. Significant progress is feasible by 2030 but require broader systemic changes.
2. Half of the reduction is achieved through mode shifting (Fig.11) and avoiding travel, while the other half comes from vehicle energy efficiency, electrification and optimisation and downsizing of vehicle fleets.
3. Large co-benefits such as improved local air pollution and public health are feasible.
4. While significant progress can be made, residual emissions from long-haul freight, aviation, and rural mobility need targeted interventions.
5. We are some way off imagining and delivering the kinds of futures we arrived at.

Recommendations

Accelerate infrastructure investment and regulatory reforms:

1. Build dedicated cycling and e-biking networks, improve public transport and expand rail and coach services.
2. Implement urban car restraint, congestion pricing and parking restrictions to encourage shared mobility and active transport. Support cleaner freight through incentives for consolidation centres, professional delivery logistics and rail or waterborne freight.

Implement comprehensive carbon pricing across transport :

1. Introduce mechanisms such as progressive road user pricing and frequent flyer levies. Research and citizen assemblies show there is public support.
2. Use the generated revenue to invest in active travel, electrify buses and freight vehicles, and ensure equitable access to sustainable transport options incl. EVs.

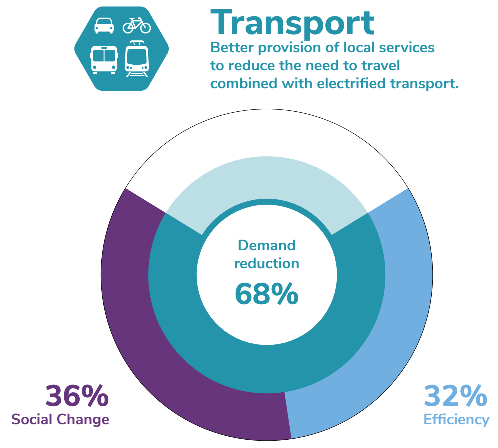


Fig. 11: The potentials for avoid & shift and efficiency strategies in reducing transport energy demand *(click to enlarge)*

Key message

Without energy demand reductions it will be virtually impossible, more expensive and probably undesirable to meet the UK's carbon targets. Lower transport energy demand supports deeper, faster decarbonisation without relying heavily on high-risk or unproven carbon dioxide removal technologies. It enhances co-benefits such as public health, air quality and reduced resource use. It will require a shift in focus from technological fixes to technological plus behavioural and structural changes.

Net Zero Societies

Future societal norms and behaviours will have a significant impact on how emissions are reduced, but they are also highly uncertain. Society in 2050 is likely to be very different from today. Testing against a wider set of assumptions about how society could look should make the UK's net zero strategy more resilient and ready to address risks and opportunities as they arise.

Findings

1. Societal change will affect the future level of demand for energy and goods and what technologies are available (Fig.12) – we found 65% difference in demand in 2050.
2. Net zero can be met in all the societies BUT meeting targets will be cheaper and less risky if societal changes reduce energy demand.
3. All societies see large efficiency improvements – largely EV roll-out. But contrasting increases in trips (car, bus, air) and distance travelled.
4. Public dialogue: Individuals would find making sustainable choices more difficult without enabling infrastructure.

Recommendations

1. Policies should be stress-tested across all scenarios to ensure resilience against varying outcomes.
2. Focus on fostering trust, innovation and coordinated action for net zero strategies.

Key message

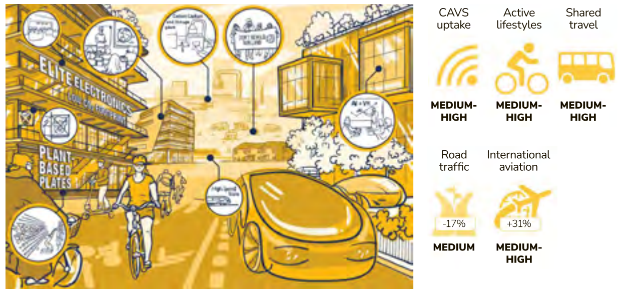
Policy makers can use scenarios to reflect on long-term net zero strategy and identify robust policies that perform well across diverse futures, ensuring resilience against uncertainty in societal trends and technological development.

Atomised society

High growth and tech progress, Low trust

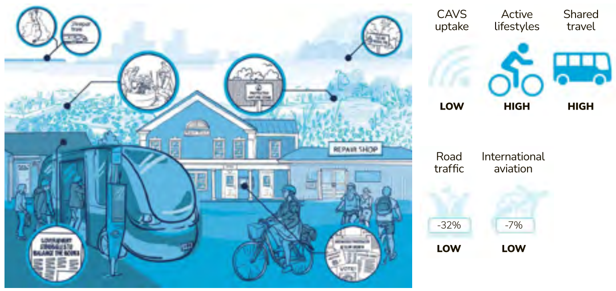
Metropolitan society

High growth and tech progress, High trust



Slow lane society

Low growth and tech progress, High trust



Self preservation society

Low growth and tech progress, Low trust

Fig. 12: Illustrations of the four 'net zero society' scenarios and pathways (GO-Science) *(click to enlarge)*

Lifestyle and Efficiency: A Case Study of Scotland

Scotland is an interesting case study because it has a more ambitious climate change mitigation policy that engages with long-term re-configuration of the transport sector, an opportunity of using subnational powers, and significant public health and air quality challenges.

Findings

1. Lifestyle change can provide earlier reductions, higher cumulative savings and lower system costs than infrastructure change.
2. At the very least lifestyle change may make the achievement of net zero carbon reductions easier.
3. Best option to meet policy targets in Scotland is combined package of radical lifestyle change and high EV pathway (Fig.13).
4. No time for wholescale infrastructure change.
5. Must deliver within the existing socio-technical system whilst fostering the need for wider system-level transformation.
6. Uncertainty remains on whether this can be achieved on the required scale and timeline.

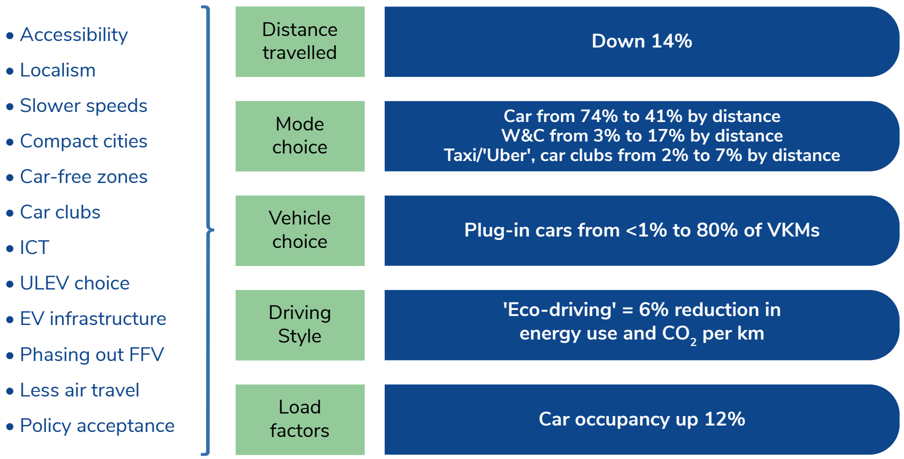


Fig. 13: Drivers and impacts of a combined lifestyle and efficiency scenario *(click to enlarge)*

Recommendations

1. Consider strategies that combine lifestyle interventions with technological advancements to effectively reduce transport emissions.
2. The urgency highlighted by the climate crisis, cost of living crisis and public health emergency underscores the need for immediate and comprehensive action beyond waiting for technological fixes.

Key message

A combined approach of relatively radical lifestyle change and high EV adoption offers earlier reductions, higher cumulative savings and lower system costs. While large-scale infrastructure change is not feasible within the required timescale, delivering within the existing socio-technical system can ease the transition to wider transformation.

Reducing Car Use

The transport sector is in danger of jeopardising the country's ability to achieve its net zero emissions targets due to insufficient progress in reducing emissions, inadequate policies, and an over-reliance on electrification and technological solutions without addressing the urgent need to reduce travel demand, particularly car use. But how much do we need to reduce car use?

Findings

1. Short-Term Need: Immediate demand reductions are necessary to meet the 68% territorial emissions reduction by 2030 under the Paris Agreement. A quadrupling of emissions reduction rates in transport is required (Fig.14).
2. Medium-Term Goal: By 2050, surface transport must achieve absolute zero emissions. Electrification and efficiency gains alone cannot close the carbon gap, making demand reduction essential.
3. Quantitative Targets: A 20-50% reduction in car mileage by 2030 and stringent control over long-distance travel emissions are required to meet interim carbon budgets and avoid overshooting cumulative emissions targets.

Supporting evidence:

- A comparison of current policies with the Climate Change Committee's sixth carbon budget (2037) shows a cumulative 182 $MtCO_2$ overshoot. Scenario modelling suggests that a 30-50% reduction in car kilometres is needed by 2030, relative to 2020, to meet the UK's 6th Carbon Budget.
- For Scotland, a 20% reduction in kilometres is needed by 2030, relative to 2019, to meet the nation's net zero target by 2045.

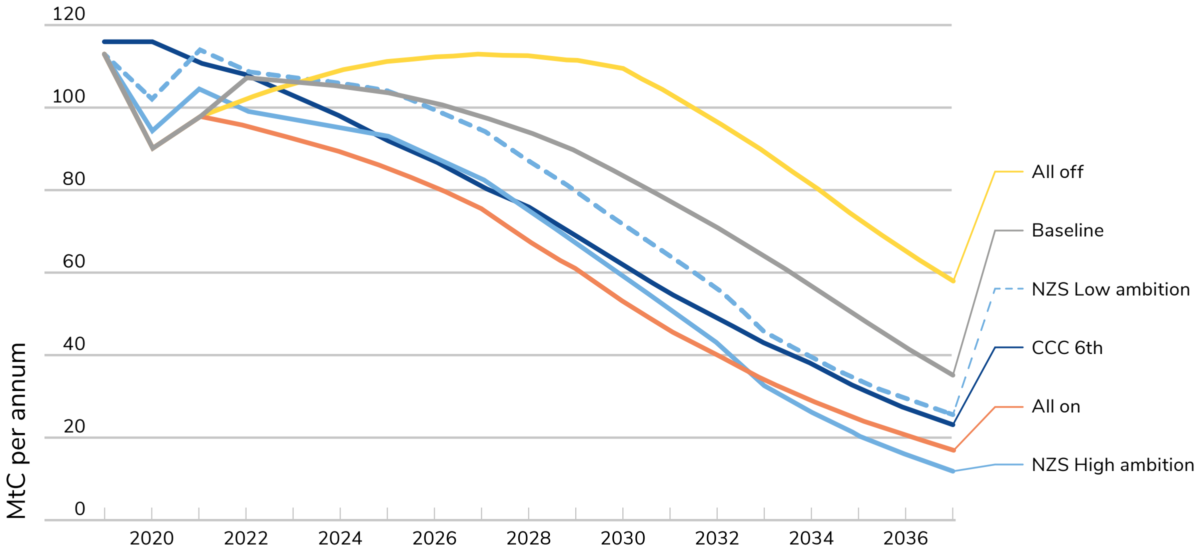


Fig. 14: Modelled emissions pathways, with and without traffic reduction (Marsden 2023)
(click to enlarge)

Reducing Car Use

Recommendations

1. **Reduce car use:** Set explicit national targets to reduce car distance travelled, similar to Scotland. Avoid focusing solely on trip substitution for short distances. Implement road user pricing mechanisms to disincentivise car travel.
2. **Shift focus to medium- and long-distance travel:** Expand rail infrastructure and prioritise electrification. Improve intermodal connections, ticketing and service reliability.
3. Strengthen delivery plans for carbon budgets with clear, quantifiable targets on demand for private car use and robust implementation timelines.

Key message

Achieving necessary deep emissions reductions will require radical and immediate changes, including demand management, restrictions on high-emission vehicles and a focus on medium- and long-distance car (and air) trips, alongside accelerated electrification and modal shift. Without such measures, the UK will fail to meet its carbon budgets and broader climate commitments.

"Given the scale of this challenge, planning for failure and exploring the synergies between concurrent adaptation and mitigation options, to create both a flexible, resilient as well as lower carbon system, would seem to be the only true meaningful pathway around which to plan a new delivery strategy."

(Anable, 2024)

Car Ownership Over Space and Time: What Can Deep Neural Networks Do?

To align transport and energy systems with decarbonisation and infrastructure resilience goals, policy and planning needs tools to assess future car ownership, particularly EVs. Here we show how deep neural networks reduce prediction error by up to 29% compared to linear regression and outperform other AI-based methods, including the DfT's own model.

Key findings

1. **Key predictors:** Car ownership patterns at fine spatial scale are influenced by demographic, socio-economic and spatial variables, including public transport accessibility, travel distances and disposable household income. These variables are interdependent, and neural networks are better at capturing their nonlinear relationships than traditional models (Fig.15).
2. **Scenario-based modelling potential:** The method enables analysis of how future changes in demographics, socio-economics, and the built environment could affect car ownership, with implications for electric vehicle (EV) adoption pathways and local infrastructure demands (Fig.16).
3. **Policy and planning integration:** Factors influencing car ownership – such as accessibility, income levels and travel patterns – can be directly shaped by policy, enabling the use of these models to explore and guide interventions.

Recommendations

1. Infrastructure planning: Explore using neural network-based models to predict localised EV adoption and assess future demands on electricity networks and transport infrastructure.
2. Prioritise investment in areas with expected rapid EV uptake to prevent bottlenecks in charging infrastructure and grid capacity.

Key message

Deep neural networks significantly enhance the accuracy of spatially disaggregated car ownership predictions, providing a vital tool for understanding pathways to decarbonising private vehicle fleets and informing transport and energy system planning for net zero goals.

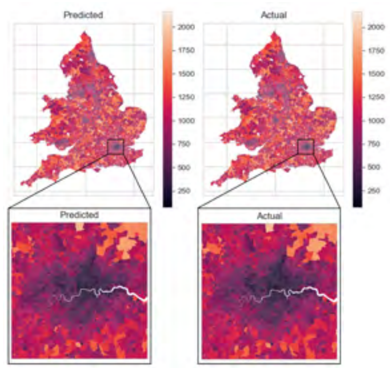


Fig. 15:
Predicted (left) and actual (right) cars per LSOA (2011)
(click to enlarge)

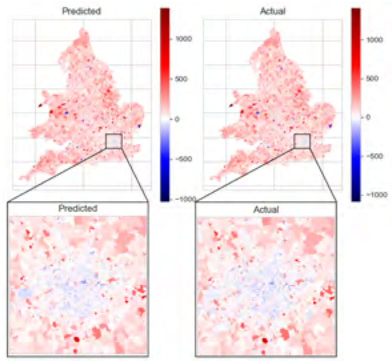


Fig. 16:
Predicted (left) and actual (right) change in cars (2001–2011) per LSOA
(click to enlarge)

Smart Urban Mobility

Smart urban mobility may help or hinder decarbonisation, depending on how well it is integrated into a broader strategy to manage transport demand and accelerate the transition to clean energy systems. Here we provide evidence on demand-side management, traffic optimisation and eco-driving measures to decarbonise urban mobility.

Key findings

1. ICT-based interventions, such as traffic flow optimization and on-road driving efficiency improvements, have the potential in the UK to reduce carbon emissions from cars (~29%, saving ~7 MtCO2) and vans (~33%, saving ~3 MtCO2) by 2050 (Fig.17).
2. Reductions in urban air pollutants are estimated at ~22% for cars and up to ~16% for vans.
3. Avoided health damage costs were in the range from £42-£130 million annually for cars and £89-£163 million for vans.
4. Emissions savings from passenger cars may be offset by increased emissions from urban van deliveries driven by online shopping, food delivery and e-commerce.
5. This growth in urban freight and delivery services is outpacing improvements in vehicle fuel efficiency.

Recommendations

1. Focus on integrating ICT measures (e.g., real-time traffic management, eco-driving feedback) with congestion-based pricing and eco-driving incentives to improve urban transport systems.
2. Prioritise reducing demand through planning and shared mobility solutions to prevent rebound effects.

Key message

Smart urban mobility technologies, through ICT-driven traffic smoothing and eco-driving, can cut urban transport emissions in UK by 10 million annually, avoid £293 million annually in health and environmental costs, but must be carefully managed to avoid rebound effects and integrated with broader electrification and demand management strategies to maximize long-term sustainability benefits.

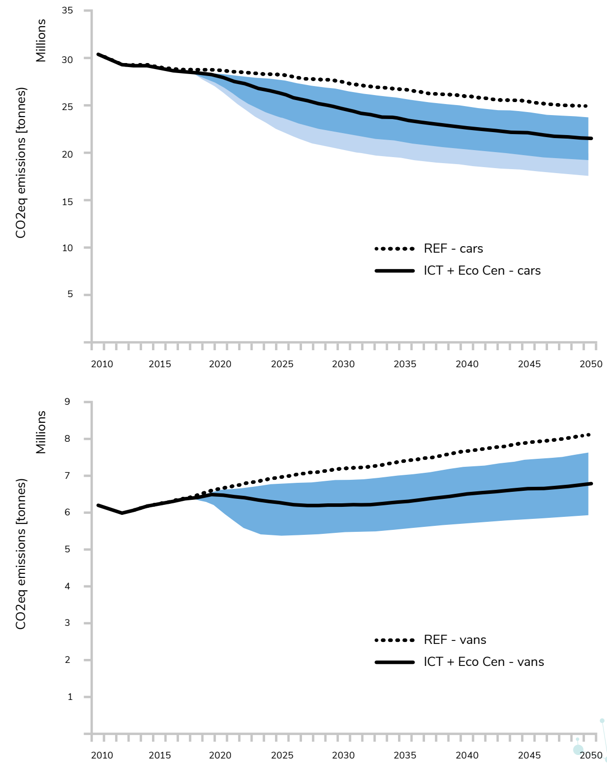
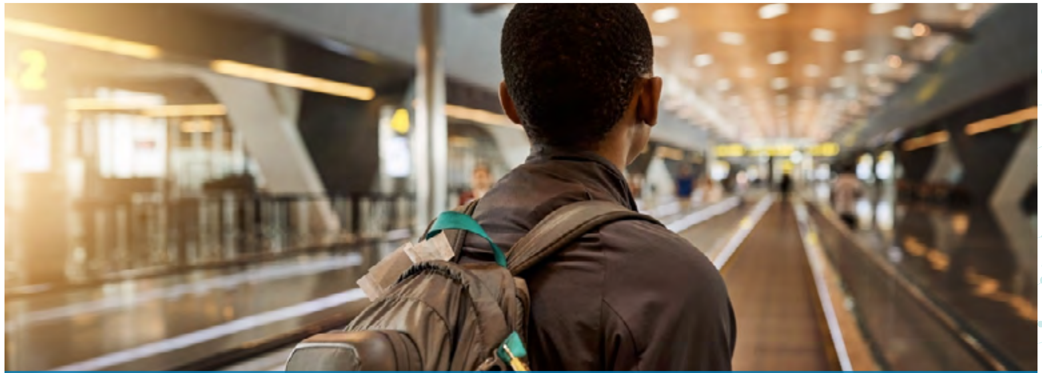


Fig. 17: CO_2e emissions for passenger cars (top panel) and vans (bottom panel) for an ambitious ICT/ eco-driving future *(click to enlarge)*

Social and Behavioural

This section highlights the key findings from the UKERC transport research and insights on reducing energy demand through social and behavioural change, supporting the policy design process for influencing an increase in uptake of sustainable travel behaviour that is fair and equitable.



Social and Behavioural Overview

What is the problem?

Reducing energy demand through social and behavioural change faces considerable challenges due to entrenched car dependency, systemic barriers and equity concerns:

1. **Car dependency and social norms:** Driving is deeply ingrained in societal routines and norms, while walking, cycling and public transport lack infrastructure, social acceptance and safety.
2. **Cognitive dissonance:** Individuals struggle to reconcile environmental benefits of sustainable travel with personal preferences or habits, leading to resistance to change.
3. **Inequity:** Rural, low-income and marginalised groups often lack access to affordable, reliable and 'smart' sustainable transport and digital services.
4. **Effectiveness:** Behaviour change campaigns are rarely sustained and scaled without systemic improvements.
5. **Rebound effects**: Travel reductions can lead to increased energy use elsewhere (e.g., leisure travel).
6. **Political resistance**: Policies like road pricing face public opposition, and transport, housing and land use strategies are poorly aligned, limiting systemic change.

What are the solutions?

1. **Design for equity:** Ensure that policies consider the needs of vulnerable groups (e.g., low-income households, rural residents) through targeted subsidies, improved accessibility and equitable distribution of infrastructure. Crucially, target behaviour change at the community level.
2. **Invest in alternatives:** Provide robust, affordable, and reliable public transport options and active travel infrastructure in urban, suburban, and rural areas to reduce car dependency.
3. **Leverage social norms:** Campaigns should focus on reshaping societal norms around sustainable travel, emphasising co-benefits like health, cost savings and community well-being.
4. **Address digital inequities:** Promote digital literacy and expand access to smart mobility tools, ensuring inclusivity for all demographics.
5. **Integrate policies:** Align transport policies with broader urban planning, housing and land use strategies to create systemic change.
6. **Sustain behavioural interventions:** Combine incentives, education and infrastructure changes to ensure long-term behavioural shifts, with mechanisms to monitor and adapt policies over time.
7. **Target rebound effects:** Pair demand reduction measures with incentives to reduce other high-carbon activities, ensuring overall reductions in energy use and emissions.
8. A combination of accessible infrastructure, equity-focused policies and long-term cultural shifts is key to driving meaningful change.

Avoid: Reducing the Need to Travel

Avoiding travel by reducing the need to travel should be at the top of the transport planning hierarchy, but it is not. Here we summarise some of the evidence on travel demand reductions that have underpinned UKERC research since 2005.

Findings

Remote working reduces commuter car trips by 25%, but social norms around presenteeism and hybrid work adoption remain barriers. Remote working benefits higher-income, office workers more than low-income or manual labour roles.

ICT tools for virtual engagement (e.g., telemedicine, e-commerce) reduces travel needs but may create rebound effects, such as increased online shopping deliveries that add to van traffic.

Compact, mixed-use urban planning reduces travel distances by enhancing accessibility to jobs and services and reducing reliance on private cars.

For older adults, investments in **local services, accessible transport and digital literacy** can enable significant travel avoidance. For younger generations, reinforcing trends toward **public transport, shared mobility and digital-first lifestyles** can ensure long-term reductions.

Any travel behaviour change strategy will be more effective if it targets change at the **community level**.

Recommendations

1. Promote flexible ‘tele-activity’ policies across sectors, ensuring digital infrastructure is available in underserved regions and for rural and disadvantaged groups.
2. Plan for compact, walkable and age-friendly urban design to reduce trip numbers.
3. Target younger people with policies that support affordable housing near jobs, public transport passes and shared mobility schemes to reinforce their low-car trends.
4. Address digital equity by investing in broadband infrastructure and digital literacy, ensuring all demographics can benefit from virtual services that avoid travel.

Key message

Reducing overall travel demand is now essential to meet climate goals. It can deliver faster than technology solutions (like vehicle electrification). Remote working, trip consolidation, e-commerce and compact, walkable urban design are some of the key strategies for avoiding journeys. Demand reduction strategies must be accompanied by efforts to address systemic and behavioural barriers (e.g., digital inequities, car dependency, car-centric mindsets).

Shift: Choosing Sustainable Transport Modes

Modal shift is highly dependent on service quality, accessibility and affordability and is strongly influenced by habits, social norms and perceived convenience. Car dependence is entrenched by factors such as urban sprawl, limited public transport options and car-oriented planning. Convenience, flexibility and cost perceptions often favour cars over sustainable modes.

Findings

1. Road user charging has consistently shifted car trips. For example, London's congestion charge reduced car trips by ~15%, with similar impacts in Stockholm.
2. Drivers are more likely to shift to sustainable modes if provided with tangible benefits, such as improved reliability or cost savings of public or shared transport.
3. Car-sharing, bike-sharing and e-scooters reduce single-occupancy car use, particularly in urban areas. Urban planning focussing on access by sustainable means has shown to improve air quality and health (Fig.18).
4. Evidence from UK cities shows active travel could realistically replace ~40% of short car trips with quality infrastructure, and ~70% with quality micromobility.
5. Low-income and rural communities often lack access to sustainable transport alternatives. Without targeted investment, modal shift policies risk deepening inequalities.

Recommendations

1. Implement planning policies that locate homes, jobs and services in closer proximity.
2. Car restraint policies need to be coupled with expansion and integration of public transport networks to make PT competitive with car travel.
3. Permanently invest in active travel infrastructure and ensure equitable distribution across regions.
4. Incentivise shared mobility through subsidies, regulatory frameworks and urban design to prioritize sustainable modes.
5. Promote workplace and community-based travel plans to encourage shifts to walking, cycling and public transport.

Key message

Evidence shows that policy needs to tackle service quality, accessibility and affordability of sustainable modes across all journey lengths and particularly for middle- to long-distance trips for social and leisure purposes. Behavioural and infrastructure interventions must be combined to encourage modal shift.

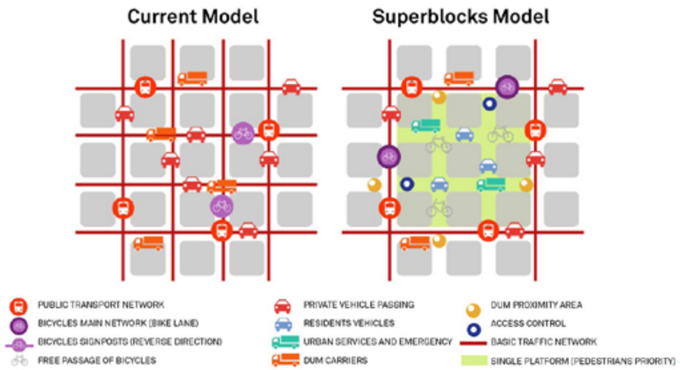


Fig. 18: Illustration of the 'superblocks' model of urban transport planning, as implemented in e.g. Barcelona
(click to enlarge)

Improve: The Efficiency and Carbon Content of Travel Choices

Improve strategies focus on enhancing efficiency and technology substitution while addressing system-wide infrastructure, equity and behavioural changes to achieve decarbonisation. This involves technological advancements, regulatory frameworks and incentivisation to shift from high-emission systems to low-carbon, resource-efficient transport solutions.

Findings

1. Beyond regulating vehicle manufacturers and advertising, changing societal preferences toward more efficient, often smaller vehicles is crucial to limit high carbon lock-in.
2. Shared mobility, such as car clubs and ride-sharing, can increase occupancy rates and reduce vehicle ownership. Higher utilisation of shared fleets reduces emissions.
3. Efficient driving through policies like road user charging, mileage-based reimbursements can lower energy intensity during vehicle use.
4. Equity-focused measures, such as progressive subsidies for EV adoption and equitable access to charging infrastructure, will ensure inclusivity in low carbon transitions.
5. Prioritising investment in accessible and interoperable EV charging networks, especially in underserved areas, can enable widespread adoption of efficient technologies.
6. The meanings people attach to car ownership – symbolic, emotional and practical – are as important as cost and environmental concerns in shaping attitudes towards EVs.
7. Improving logistics to optimise freight load factors and encouraging the transition to zero-emission trucks and delivery vehicles can improve efficiencies by about 8-10%.
8. EV adoption is influenced by distinct consumer segments, each characterised by different attitudes, demographics and preferences.

Recommendations

1. Implement tax incentives for efficient vehicles and restrictions on high-energy-demand models like large SUVs.
2. Tailor policies and marketing strategies to distinct consumer segments to help accelerate the transition to EVs.
3. Address deeper cultural and personal factors to accelerate EV adoption.
4. Road pricing to counter cheaper travel by EVs and long-standing trend of cheaper motoring vis-à-vis the alternatives.
5. Social marketing campaigns and public discourse (“SUV shaming”) to help shift consumer attitudes and normalise lightweight vehicles.
6. Expand shared mobility options beyond cities. Focus on normalising shared travel behaviour through social norms and digital nudges.
7. Eco-driving techniques for existing drivers, with insurance discounts.

Key message

Any successful *Improve* strategy involves shifting societal norms, addressing equity concerns and engaging communities in the transition. Combining technological advances with behavioural interventions can maximise benefits, avoid unintended consequences and ensure a just and inclusive transition.

Health: Air Pollution, Physical Activity and Wider Economic Impacts of Decarbonisation

This section highlights the key findings from the UKERC transport research on the air pollution, physical activity and wider economic impacts of decarbonisation, supporting the policy design process for influencing a decrease in road traffic and an increase in uptake clean and healthy transport modes and services.

Health Overview

What are the issue?

1. Beyond CO2, transport is also a major contributor to ultrafine particulate matter (PM2.5) and nitrogen dioxide (NO2) emissions, which are linked to respiratory and cardiovascular diseases, cancer, and premature deaths.
2. Around 10,000 premature deaths per year in the UK are attributed to road transport air pollution.
3. Diesel vehicles disproportionately contribute to harmful emissions, particularly in urban areas.
4. The reliance on motorised transport contributes to physical inactivity, obesity and associated non-communicable diseases like type-2 diabetes, stroke, and coronary heart disease.
5. High traffic levels and congestion can lead to stress and anxiety, while poor urban environments discourage outdoor activity and social interaction.
6. Disadvantaged communities often bear the brunt of transport-related health impacts, living closer to busy roads with higher exposure to pollution and fewer opportunities for active travel.

What are the potential solutions?

1. Accelerating the adoption of EVs through Norway-style incentives and reliable charging infrastructure, combined with measures like low-emission zones and road pricing, can significantly cut emissions.
2. Provide financial incentives for scrapping older diesel vehicles.
3. For freight and logistics, shifting to cleaner last-mile delivery options (e.g., cargo bikes, e-vans) and optimising freight systems can reduce air pollution and traffic.
4. Promote active travel with networks of high-quality infrastructure and Dutch-style investments in active travel and e-micromobility.
5. Invest in public transport electrification and improved accessibility beyond urban areas. Transition all buses, trains and trams to electric or hydrogen-powered systems.
6. Implementing demand management policies, such as congestion pricing, low-emission zones and diesel car-free zones, to reduce urban traffic and pollution.

Air Quality Impacts of Net Zero

The net zero pathways by the CCC can have significant air quality and health co-benefits. Advanced modelling techniques provide a high-resolution analysis of both spatial and temporal trends in air pollution and physical activity, highlighting the distribution of benefits across socioeconomic groups and geographic regions.

Findings

1. Net zero policies **substantially reduce toxic air pollution** (Fig.19), mainly through accelerated uptake of zero emission vehicles, the early phase-out of internal combustion engines and reduced vehicle traffic.
2. Proximity to roads increases exposure, implying urban populations benefit comparatively more from reductions in traffic-related emissions.
3. Outdoor air pollution **exposure inequalities across socioeconomic groups remain**.
4. **Non-exhaust emissions (e.g., tyre and brake wear) remain a persistent issue**, especially as EVs and future SUVs are expected to be heavier than the incumbent vehicle fleet.
5. Net zero scenarios include relatively modest shifts to active travel, with larger gains coming from electrification rather than reductions in car dependency. This results in more **moderate benefits from physical activity** compared to air quality improvements.

Recommendations

1. Urban areas experience the largest and fastest health benefits from transport decarbonisation, but achieving equity requires targeted interventions in suburban and rural regions.
2. Policy efforts should emphasize short-term actions (e.g., rapid electrification, clean air zones) and longer-term infrastructure change.
3. Scaling up active travel initiatives is critical to complement air quality improvements from electrification, with investments focused on underserved areas.
4. Tackling non-exhaust emissions will require further technological innovations (e.g., lighter vehicle materials).

Key message

Net zero climate policies in the UK offer significant health co-benefits by reducing NO2 and PM2.5 air pollution, particularly through the transition to EVs and reduced vehicle kilometres. PM2.5 pollution remains an issue but is less pronounced than previously thought. Inequalities in exposure to outdoor air pollution remain a challenge, though net zero policies help mitigate them to some extent. Shifts to cycling and e-biking provide health benefits for those who travel more actively.

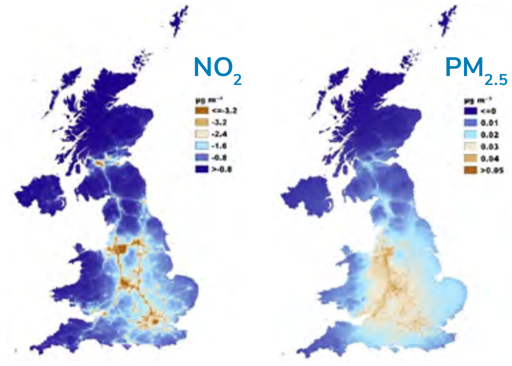


Fig. 19: Change in NO2 and PM2.5 concentrations in 2040, the CCC's 'Widespread Innovation' scenario *(click to enlarge)*

Health Impacts of Net Zero

Improved air quality reduces mortality and the incidence of major health conditions, such as COPD, childhood asthma and potentially dementia, which significantly alleviates the burden on healthcare systems and society. Increased physical activity, primarily through active travel, reduces mortality and the prevalence of chronic diseases such as type-2 diabetes, stroke and breast cancer, while promoting broader health and wellbeing.

Findings

1. Reductions in air pollution under the Balanced Net Zero Pathway led to 3.8 million life-years gained across the UK population by 2154.
2. The policies prevented an estimated 201,000 cases of chronic obstructive pulmonary disease (COPD) and 192,000 cases of childhood asthma, conditions with substantial health and economic burdens (Fig.20).
3. Dementia-related benefits were substantial in sensitivity analyses, reflecting the growing evidence of air pollution's role in neurological conditions via cardiovascular and inflammatory pathways.
4. Increased cycling and e-biking led to a 4.8–6.6-fold rise in physical activity compared to 2019 levels, while walking increased modestly. These changes in physical activity contributed 1.1 million life-years gained by reducing risks for diseases such as type-2 diabetes, stroke and breast cancer.
5. Benefits were particularly pronounced among new and less active users, highlighting the importance of promoting active travel across all groups.

Recommendations

1. Climate and health policies should **explicitly consider mortality and morbidity co-benefits** from air quality improvements (e.g., COPD, asthma, dementia) and increased physical activity (e.g., diabetes, stroke, cancer).
2. **Target diverse population groups**, including underrepresented and less active individuals.
3. Prioritise interventions in areas with **high baseline exposure** to air pollution.
4. **Promote e-bike adoption paired with safe infrastructures**.
5. **Address health disparities** related to socioeconomic status, geography and pre-existing vulnerabilities.

Key message

Net zero pathways deliver profound health benefits across multiple impact pathways, including lower mortality rates, fewer cases of chronic and acute diseases and substantial economic savings, underscoring their critical role in public health and policy-making.

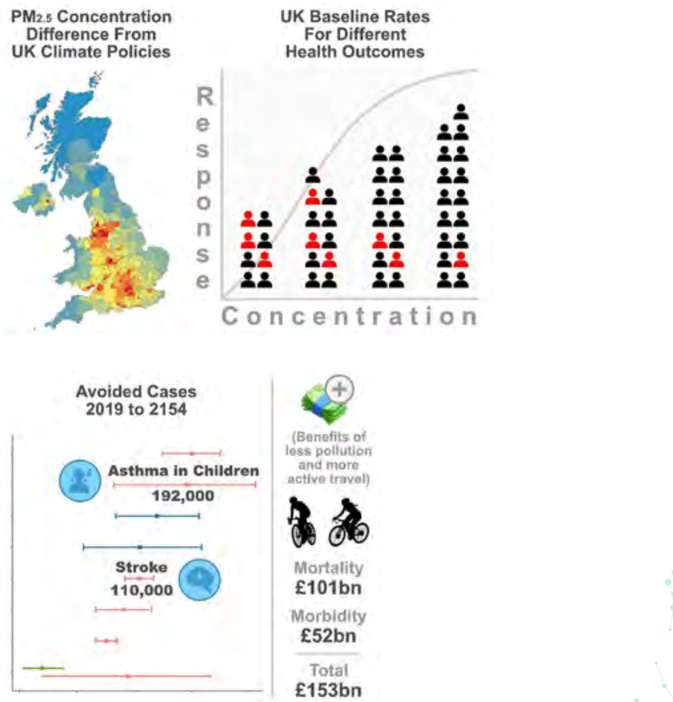


Fig. 20: Health and associated economic benefits of reduced air pollution and increased physical activity from climate change policies *(click to enlarge)*

Economic Impacts of Net Zero

This theme provides evidence of the health economic costs and benefits from changes in air pollution and physical activity of the UK net zero pathways. We argue for the urgent need to integrate health considerations into climate policy design for maximised societal benefits.

Findings

1. Net zero policies in the transport sector are cost-effective, with break-even achieved through health and air pollution benefits alone (Fig.21).
2. Transport electrification drives improvements in air quality health outcomes, doubling co-benefit estimates if NO2 reductions are included.
3. The CCC's Balanced Net Zero Pathway achieves health co-benefits valued at £9.1 billion by 2050 and £36.5 billion by 2154. However, by 2040, the transport sector was three times less effective at reducing PM2.5 than the buildings sector due to non-exhaust emissions from road vehicles.
4. Mortality economic benefits from reduced air pollution outweigh those of increased physical activity, as net zero scenarios emphasize fleet electrification over mode shifts.

Recommendations

1. Strengthen policies to accelerate fleet electrification, ensuring strong support for technological innovations like regenerative braking, low emission tyres and road surfaces.
2. Justify net zero policies with long-term economic savings by emphasising avoided health costs.
3. Incorporate these long-term benefits into policy appraisal frameworks.
4. Launch public campaigns highlighting health-economic benefits of net zero policies to garner public and political support.

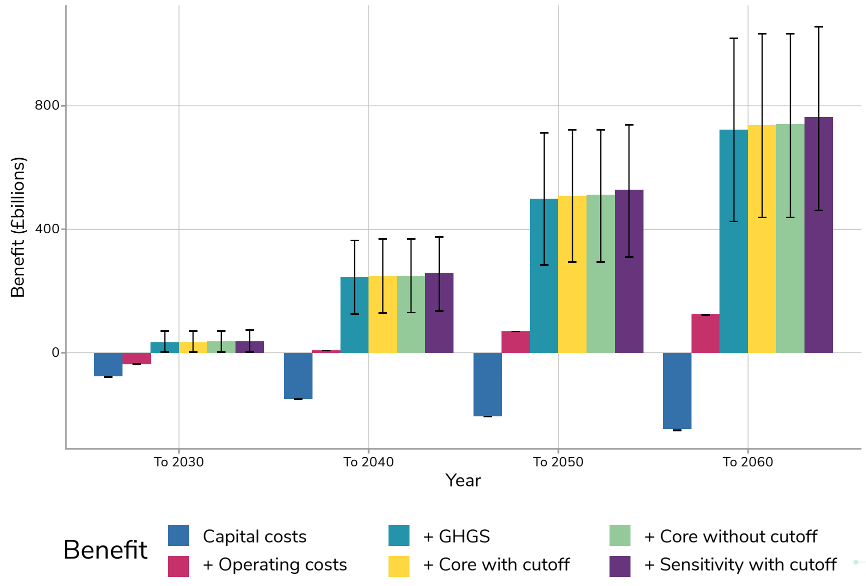


Fig. 21: Net economic benefits for the transport sector under the BNZP scenario
(click to enlarge)

Key message

The cost-benefit analysis strongly supports the urgency of ambitious net zero transport policies. By embedding health and economic co-benefits into policymaking, targeting inequalities, and addressing shortfalls in active travel and indoor air quality, net zero policies can deliver transformative benefits for climate, public health and social equity.

The Health Economic Costs of Cars and Vans

We know there are severe health consequences of the UK's reliance on motorised travel, particularly in urban areas. Existing strategies, plans and measures will only deliver the pollutant emissions reductions needed to meet UK air quality standards for NOX by the late 2020s. Here we provide evidence of the health damage costs of exposure to ultrafine particulate matter (PM2.5) and nitrogen dioxide (NO2), including costs from early deaths, hospital admissions and treatment for air pollution related illnesses.

Findings

1. Air pollution from cars and vans imposes an annual health cost of about £6 billion on the UK, more than a quarter of the total UK health damage costs from air pollution.
2. **Nearly 90%** can be attributed to **diesel** vehicles.
3. The health costs from air pollution attributed to a typical UK car over its 14-year lifetime amount to about £1,640 (Fig.21), while a van costs £5,107 over its 9-year lifetime.
4. But health damage costs from diesel vehicle emissions are about 20 times greater than those from electric vehicles and at least five times greater than those from petrol vehicles.
5. Health damage costs are most acute in urban environments, particularly in densely populated cities. In inner London, lifetime health costs rise to £7,714 and £24,004 for fossil fuel cars and vans respectively.
6. If every new car were electric it would save about £325 million in health costs in the first year.

Recommendations

1. Implement Norway-style incentives and infrastructure development to accelerate EV uptake and phase out diesels.
2. Further expand and enforce ultra low emission zones in densely populated cities.
3. Educate the public on the health impacts of vehicle emissions and the benefits of alternative modes of transport to foster lasting change.

Key message

The health costs of air pollution from cars and vans in the UK are substantial, with vehicle emissions burdening the NHS and society by more than £6 billion annually. Nearly 90% of this can be attributed to diesel vehicles, underscoring the urgent need to reduce car and van traffic and to transition from diesel to electric vehicles.

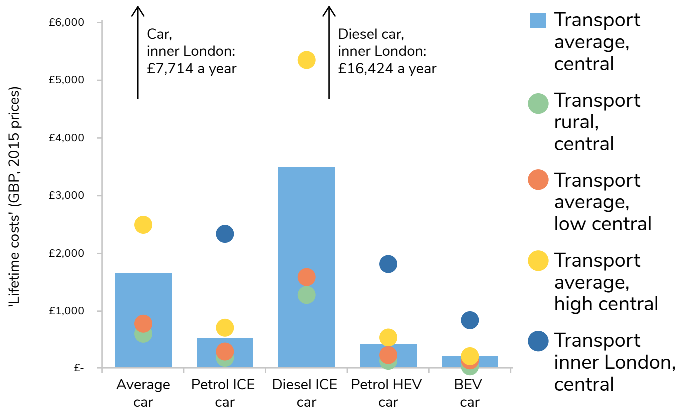


Fig. 22: Lifetime health damage costs of cars *(click to enlarge)*

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Fig 1: UK domestic transport emissions breakdown by mode in 1990 and 2019
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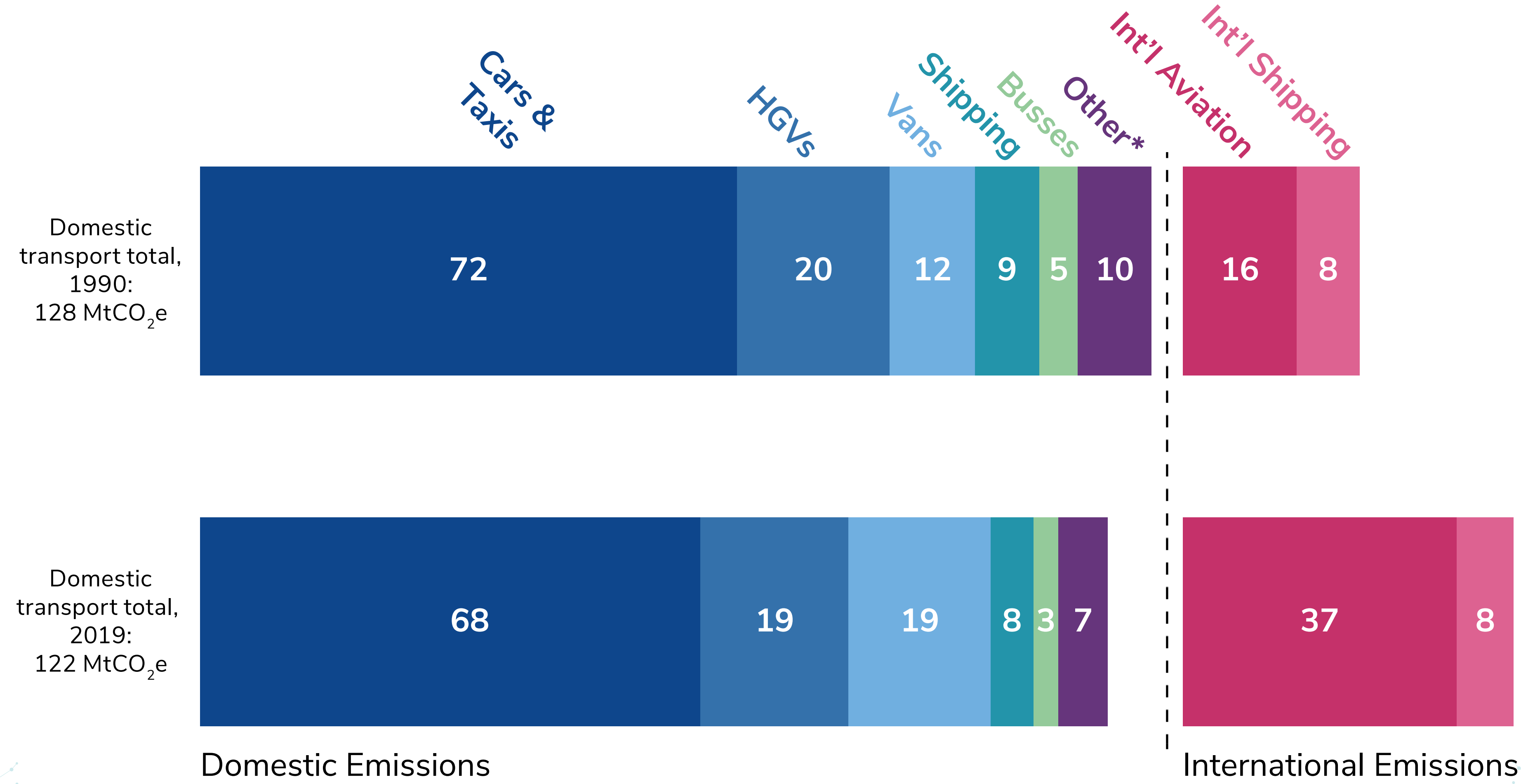

* Comprises, in 2019: Rail, 1.4%; Domestic Aviation, 1.2%; Motorcycles and mopeds, 0.4%; other transport, 1.9%

Example: illustration of a plausible societal scenario for the future UK transport system
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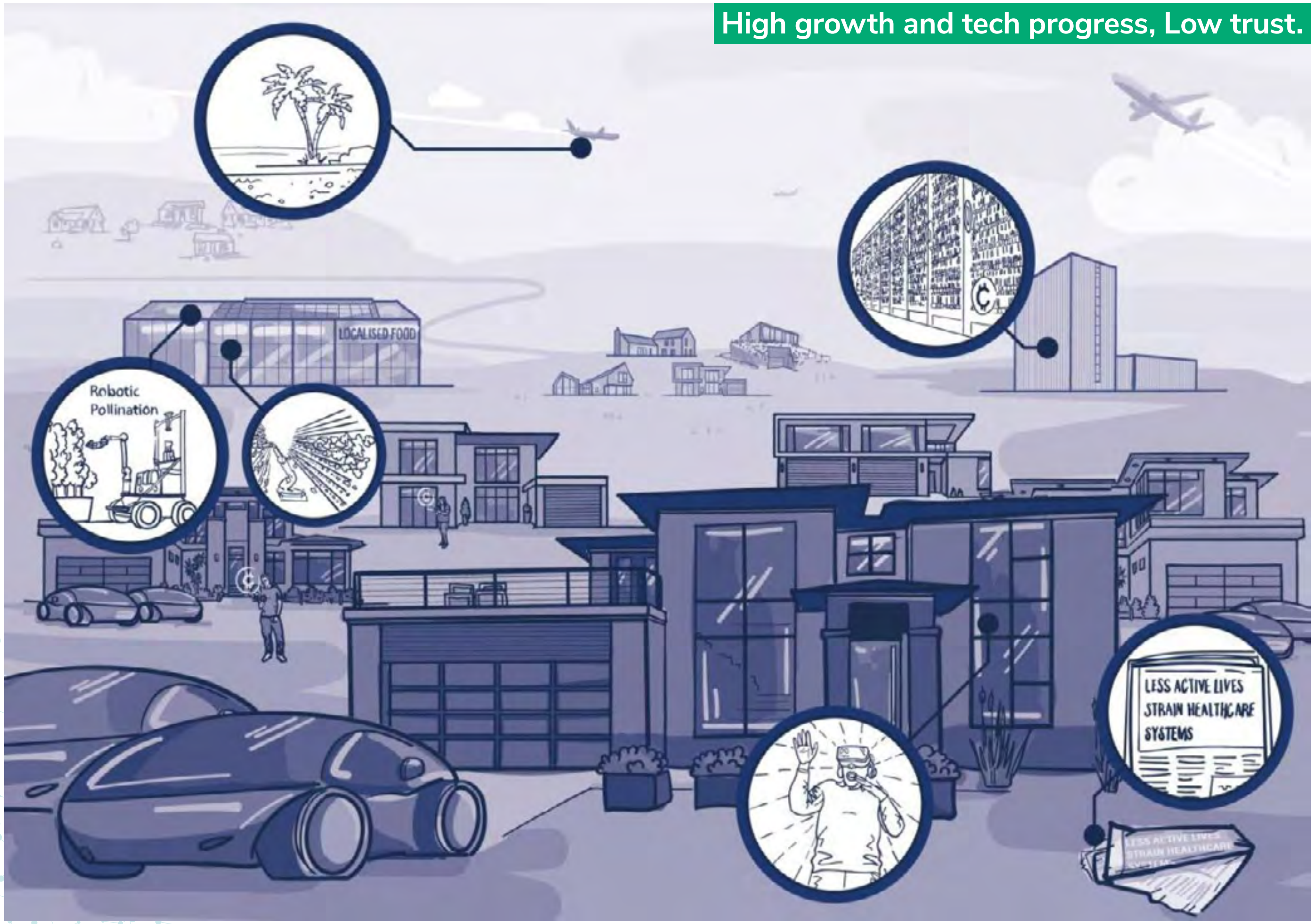

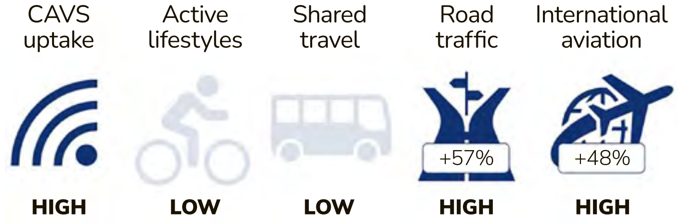

Fig. 2: Modelled projections of ICE cars in the UK - total car stock by phase out dates and type of 'ICE ban'
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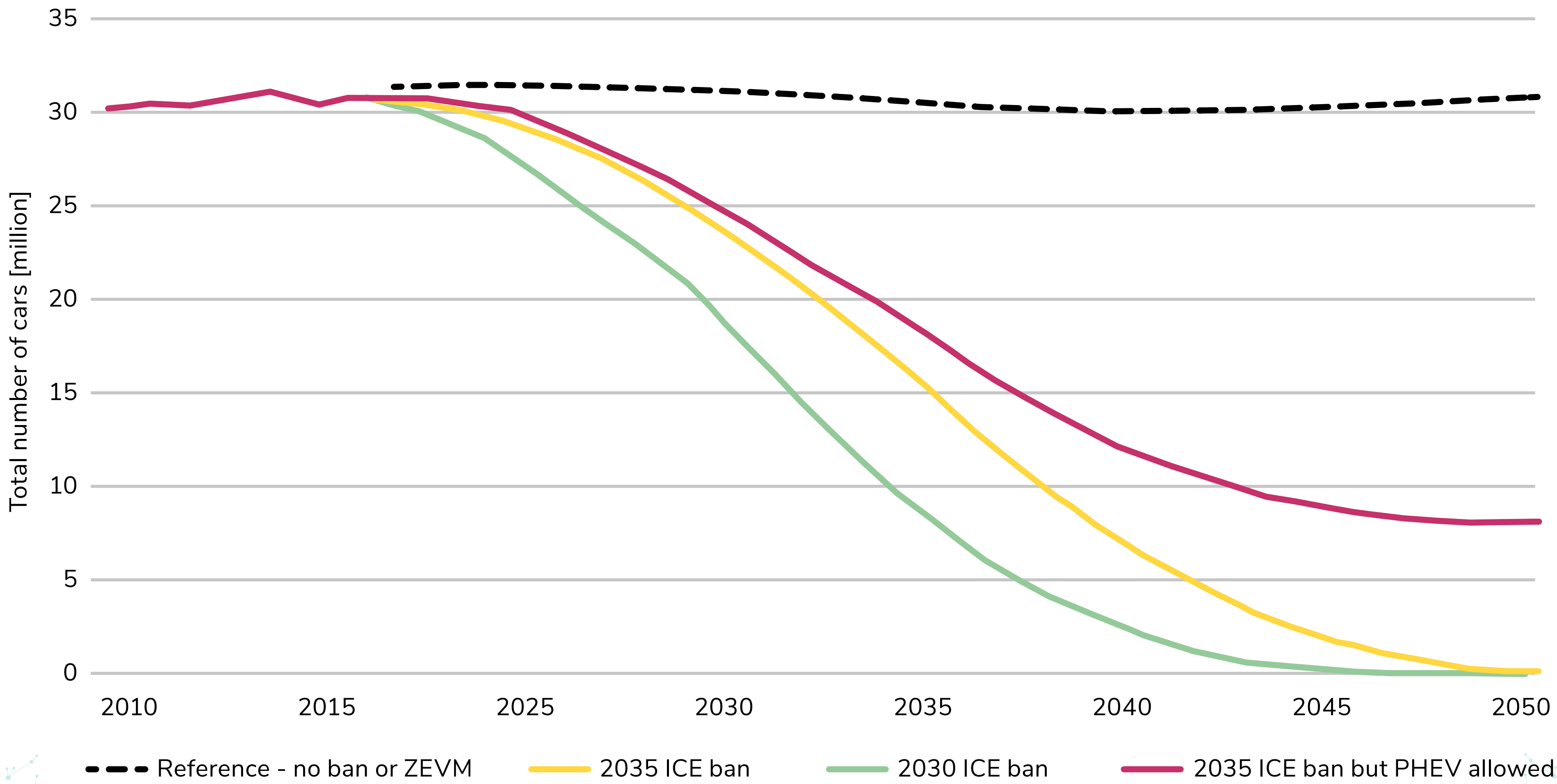

Source: adapted from modelling by Barrett et al (2022)[8] with additional analysis by UKERC (2021)[41]

Fig. 3: CO_2 effects of phased car market transformation
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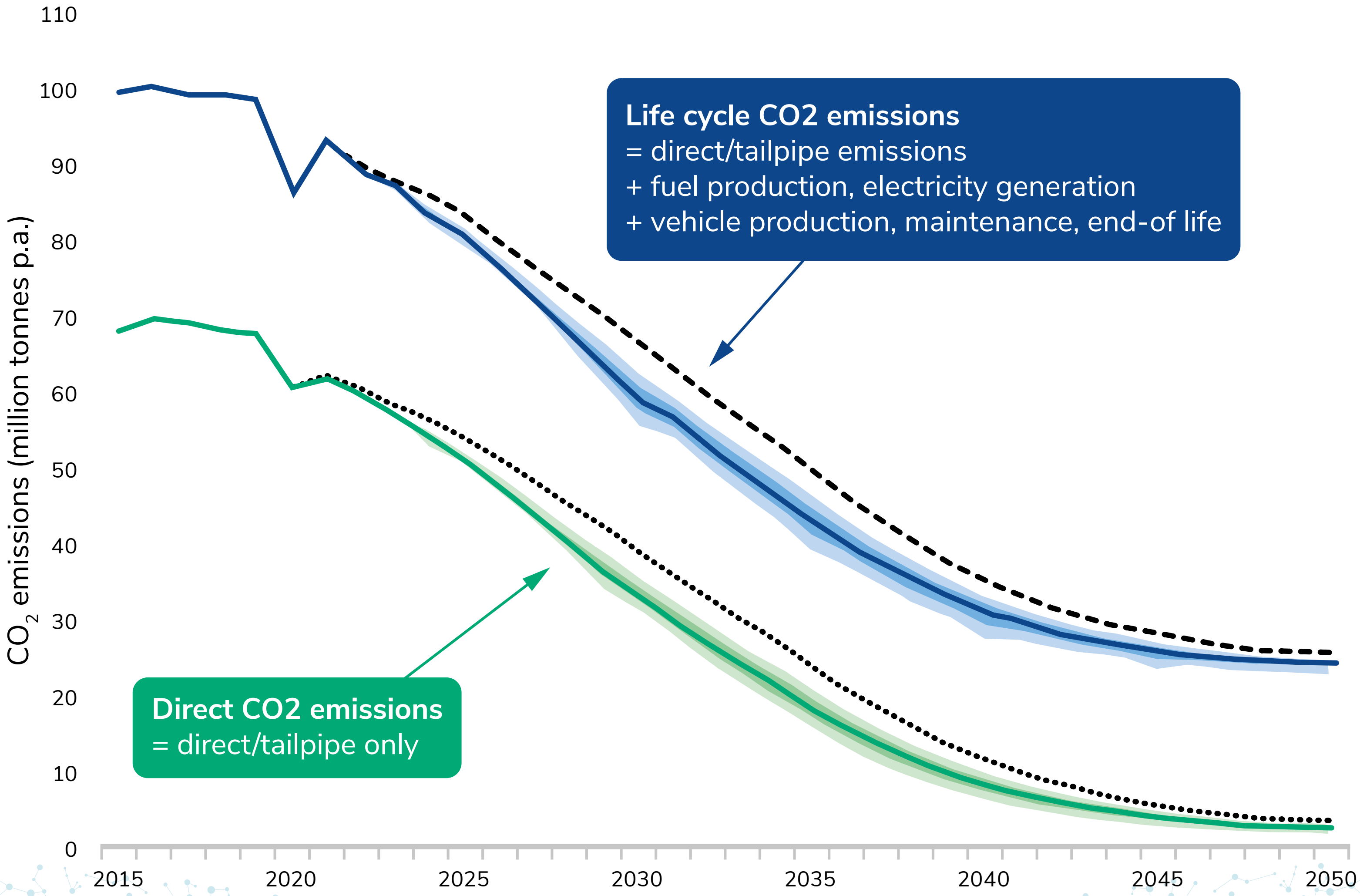

Fig. 4: New car sales by primary fuel and propulsion technology
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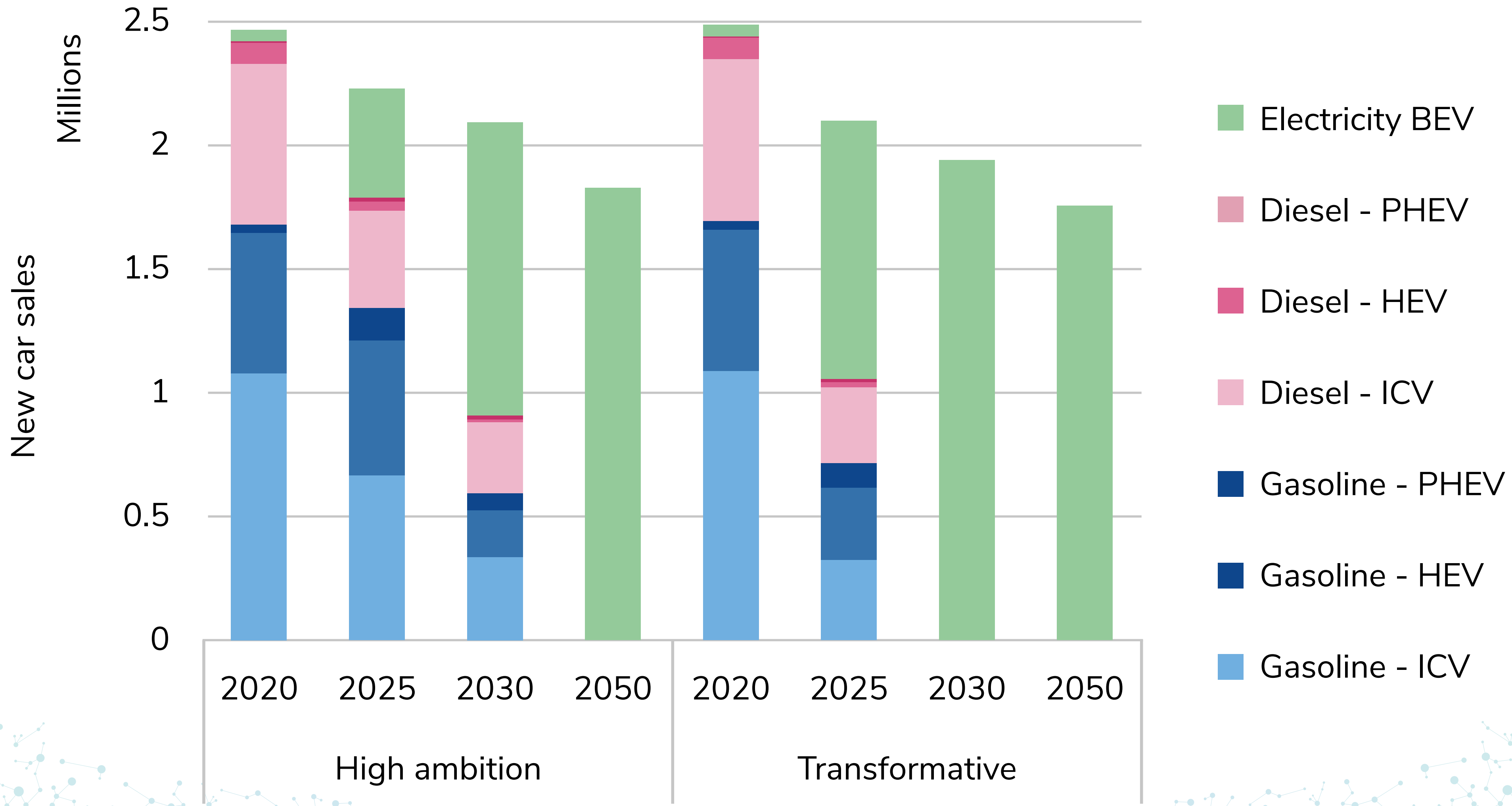

Fig. 5: Comparison of average price paid for baseline (uncontrolled) and V2G-controlled EV charging. Routine: EV always plugged in on arrival. Minimal: only when needed.
Dixon J. et *al.* 2022, *eTransportation* 13. https://doi.org/10.1016/j.etran.2022.100180

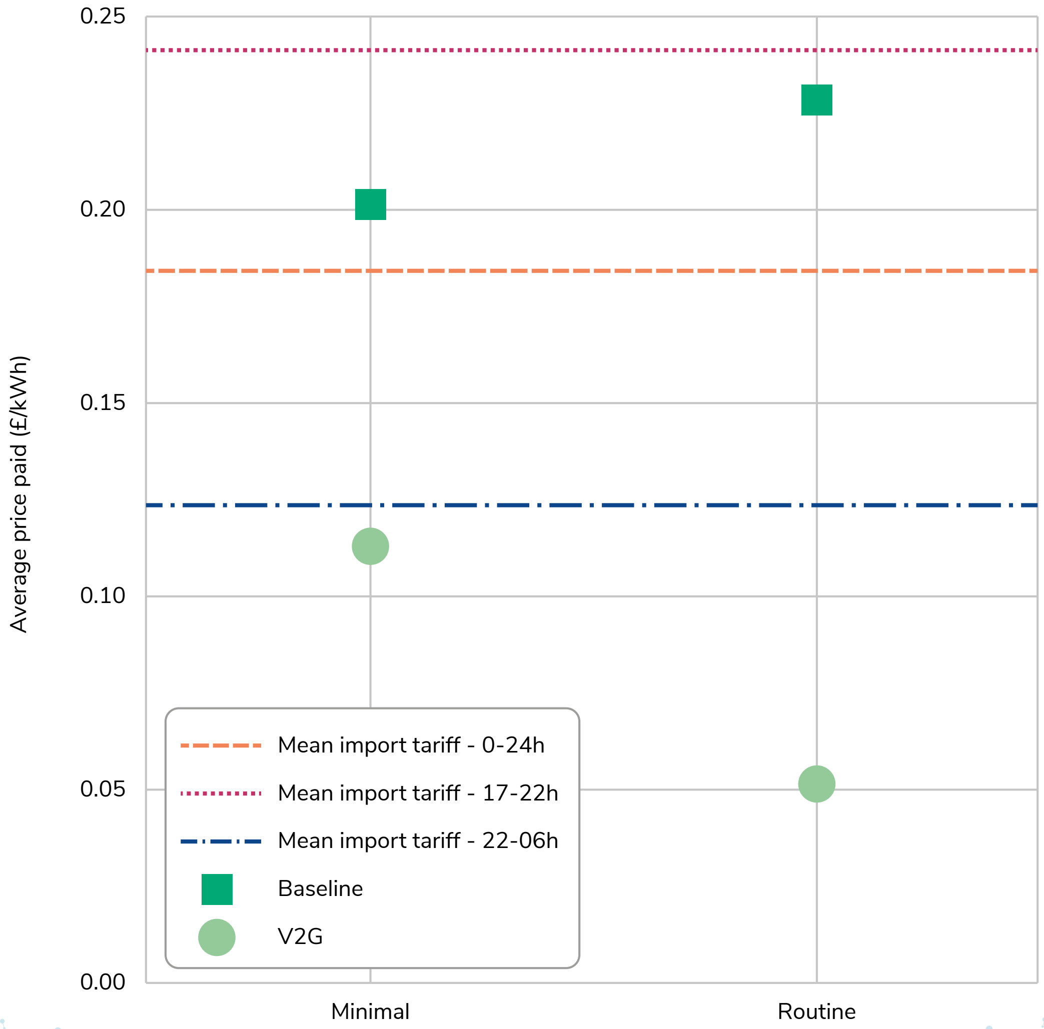

Fig. 6: Changes in evening peak load for dumb, smart and V2G
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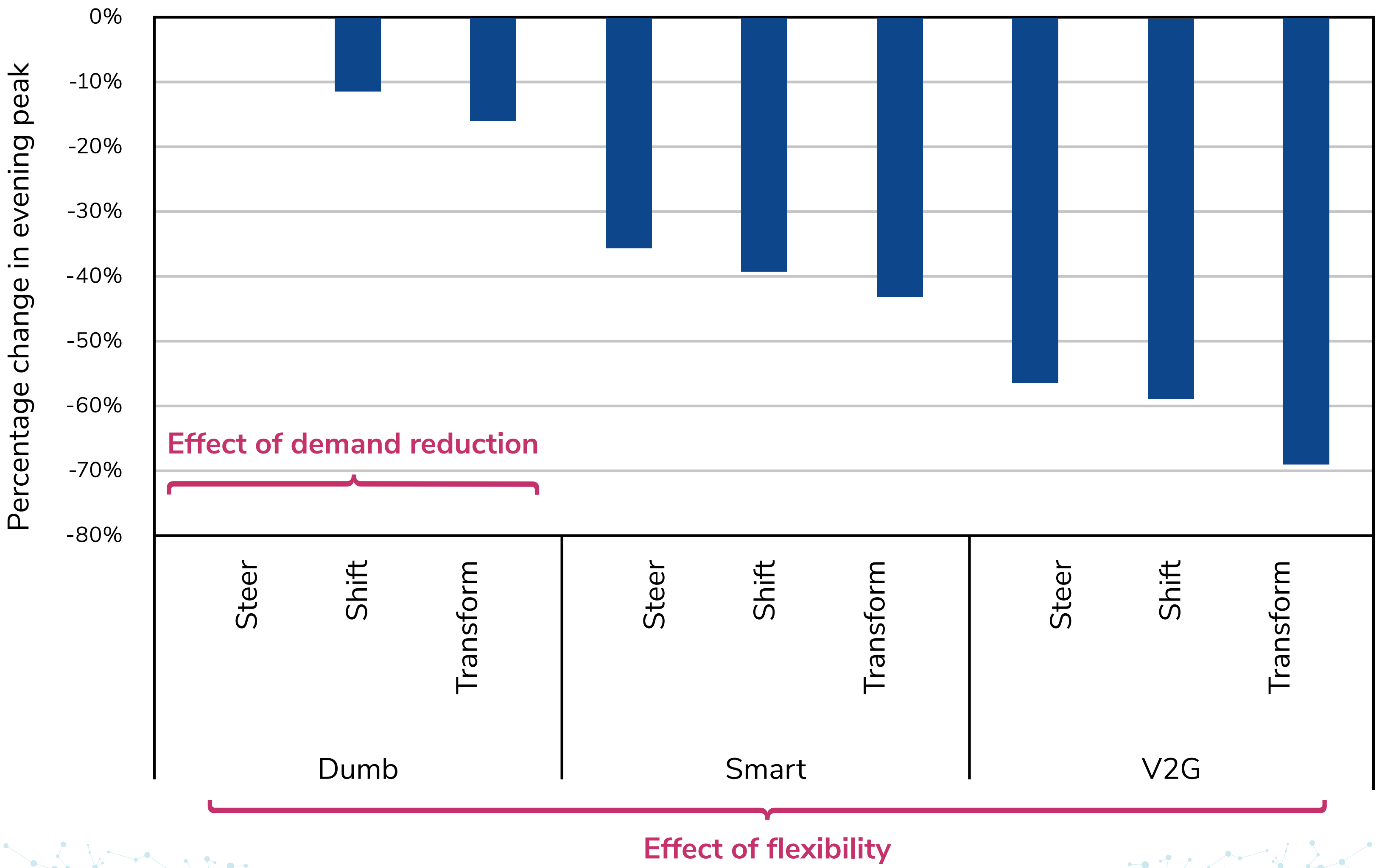

Fig. 7: Changes in emissions per additional trip (kgCO_2 / day)
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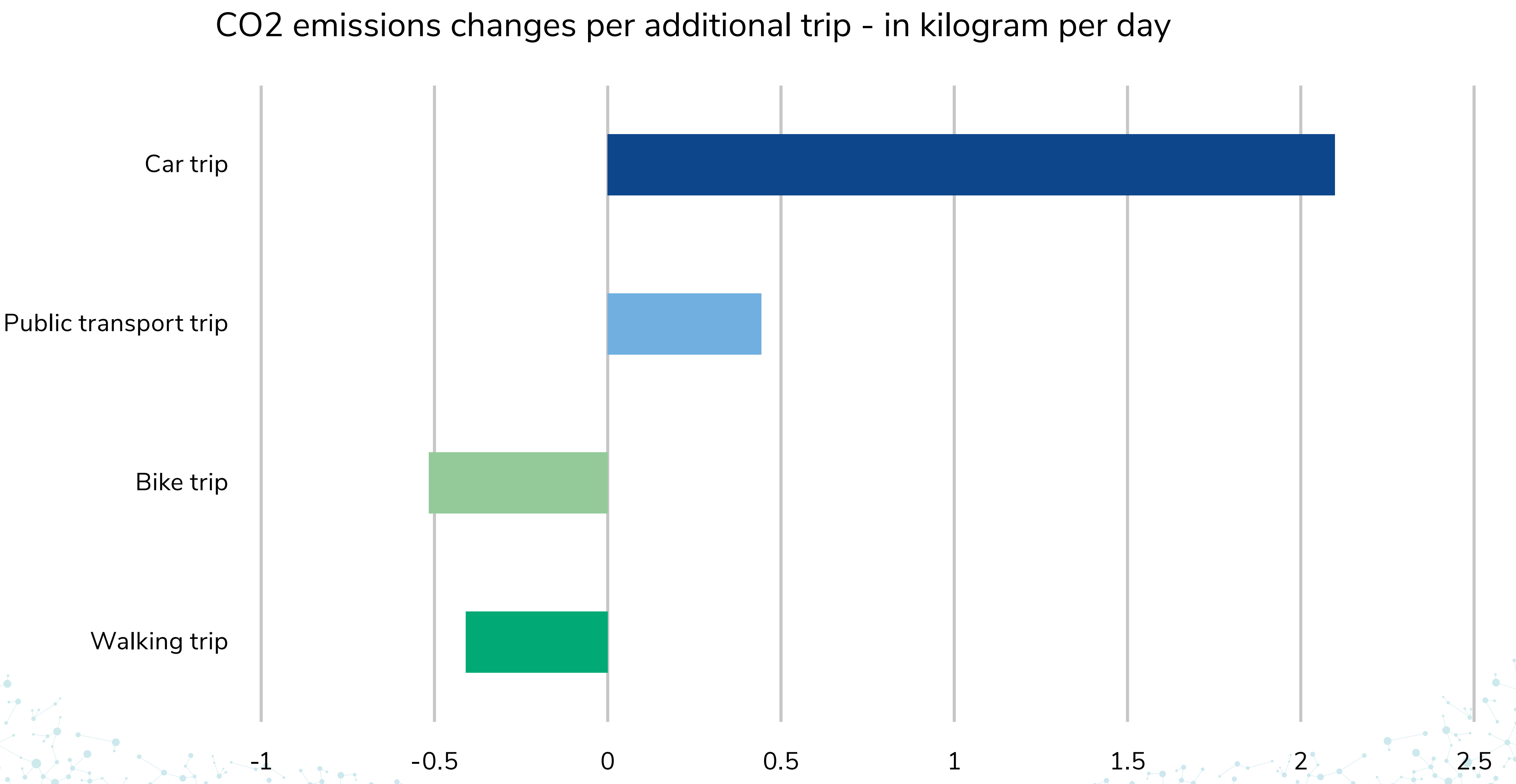

Fig. 8: Shares of trips, miles and CO_2e emissions per capita by mode (Wadud et al 2024)
Wadud, Z. et *al*. 2024, *Nature Energy* 9. https://doi.org/10.1038/s41560-024-01561-3

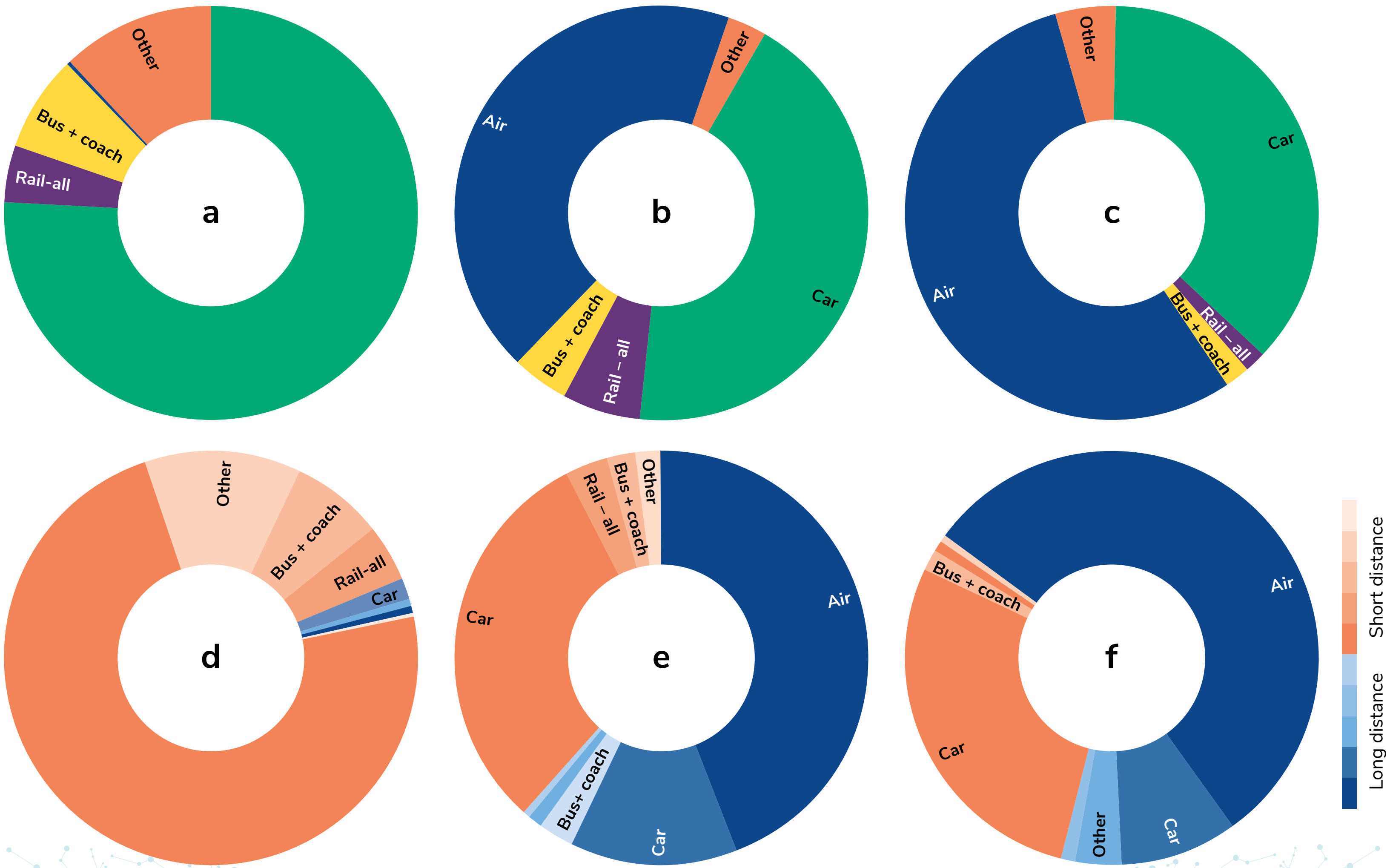

Fig. 9: The main strategic priorities for surface freight decarbonisation
Decarbonising UK Freight Transport Network 2023. https://decarbonisingfreight.co.uk/wp-content/uploads/2023/10/Decarbonising-UK-Freight-Transport-final-report.pdf

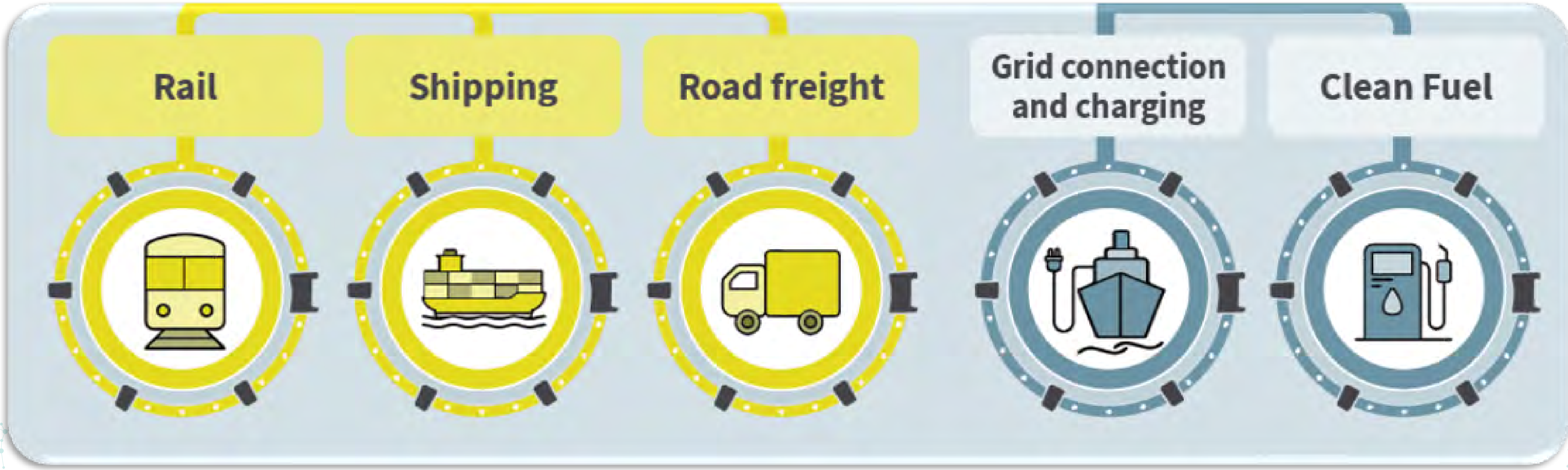

Fig. 10: A multi-sector, multi-disciplinary, whole systems approach to model low energy futures
Barrett, J. et *al.* 2022, *Nature Energy* 7. https://doi.org/10.1038/s41560-022-01057-y

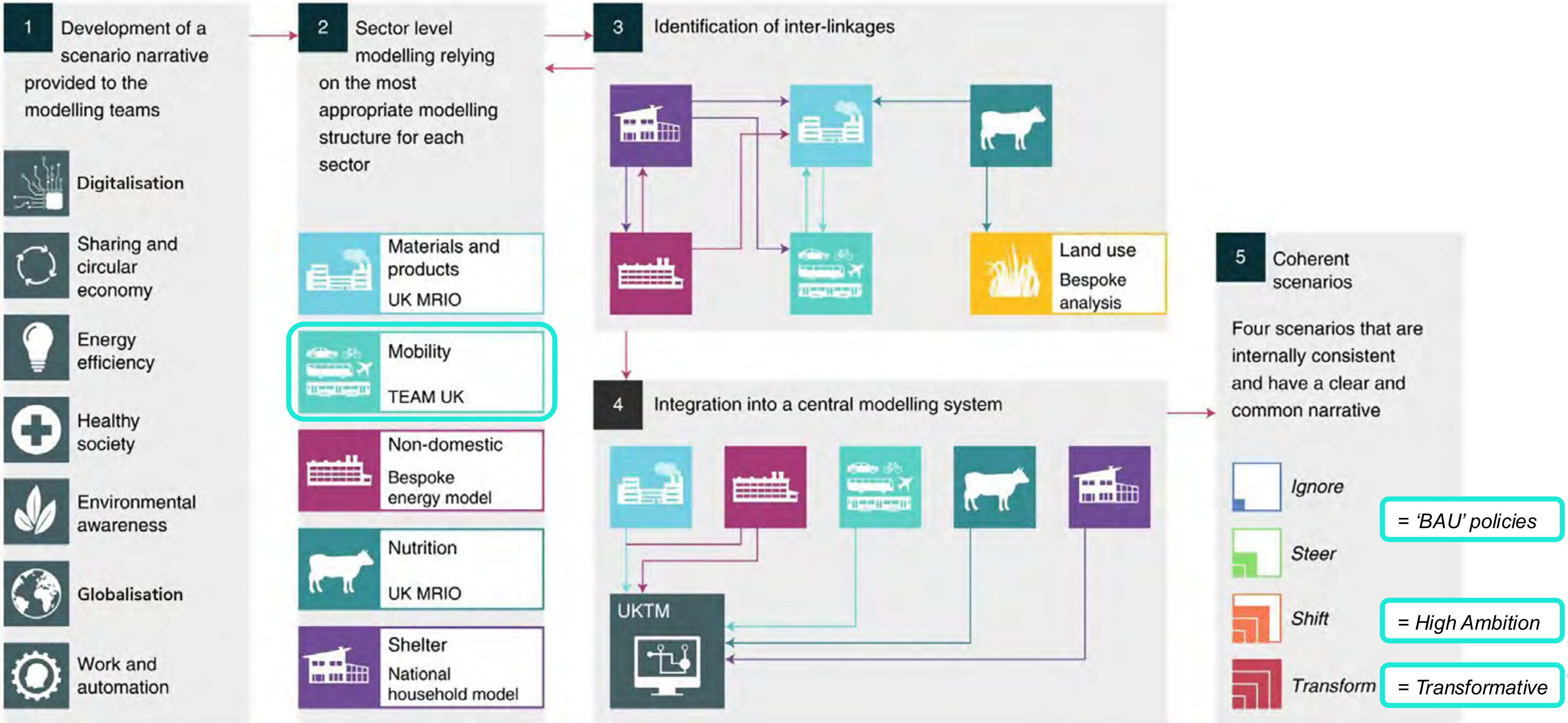

Fig. 11: The potentials for avoid & shift and efficiency strategies in reducing transport energy demand
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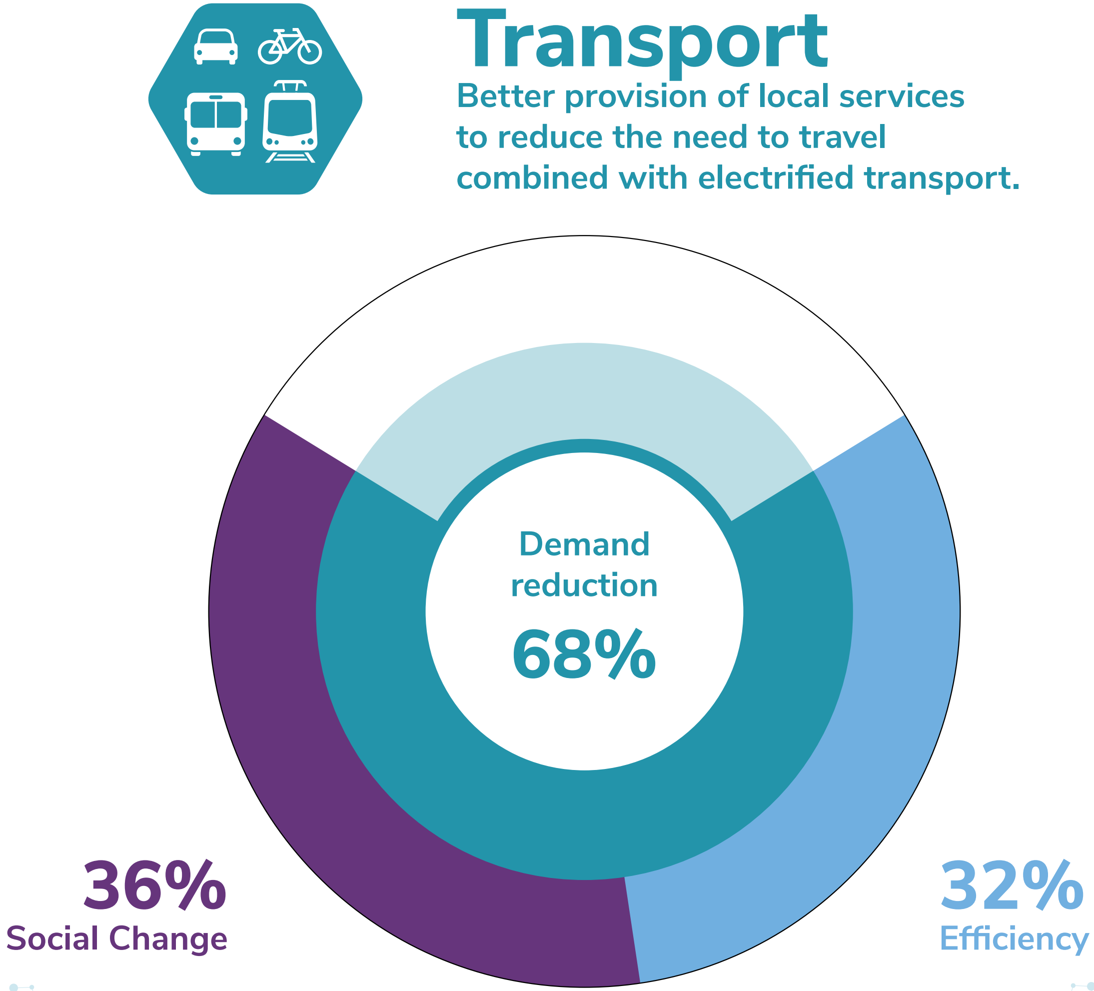


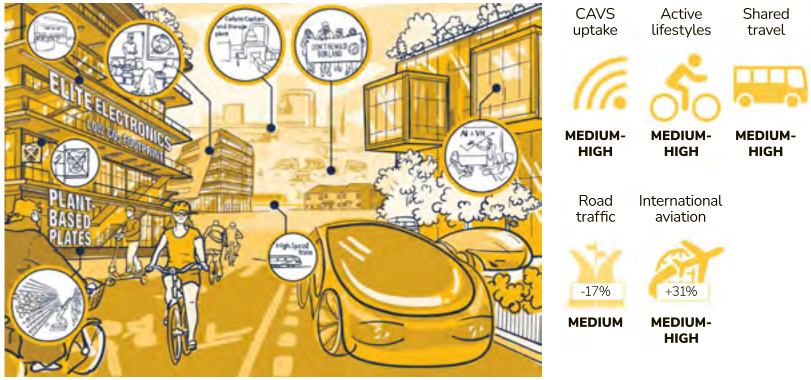
Fig. 12: Illustrations of the four 'net zero society' scenarios and pathways (GO-Science)
Government Office for Science, 2023. https://www.gov.uk/government/publications/net-zero-society-scenarios-and-pathways--2

Atomised society

High growth and tech progress, Low trust

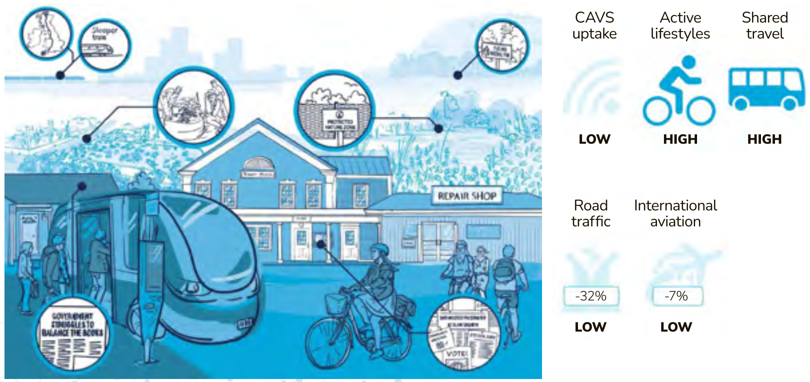
Metropolitan society

High growth and tech progress, High trust



Slow lane society

Low growth and tech progress, High trust



Self preservation society

Low growth and tech progress, Low trust

Fig. 13: Drivers and impacts of a combined lifestyle and efficiency scenario
Brand, C. et *al.* 2019, *Energy Efficiency* 12. https://doi.org/10.1007/s12053-018-9678-9

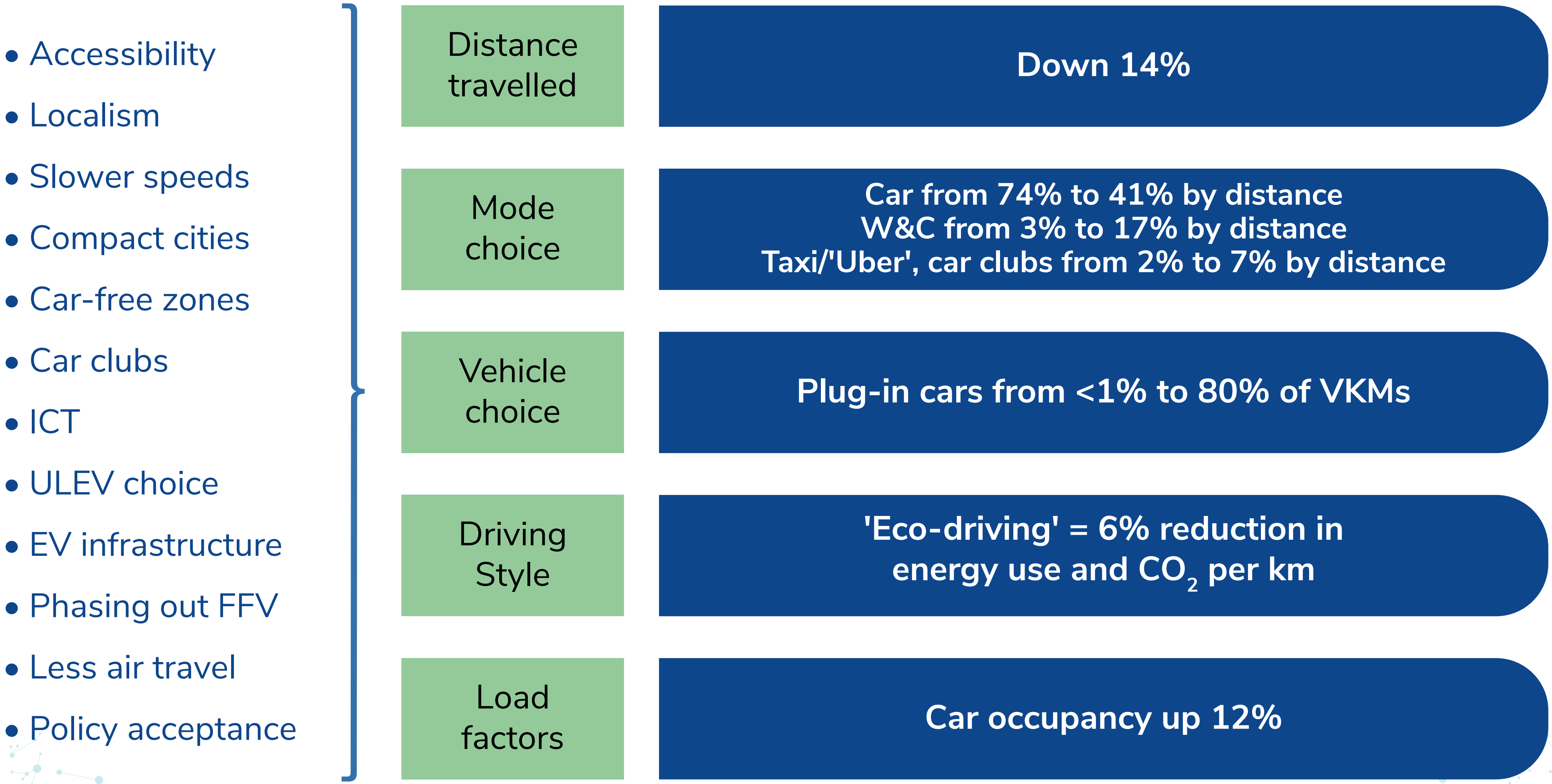


Fig. 14: Modelled emissions pathways, with and without traffic reduction (Marsden 2023)
Marsden, G. 2023, CREDS report. https://www.creds.ac.uk/publications/reverse-gear-the-reality-and-implications-of-national-transport-emission-reduction-policies/

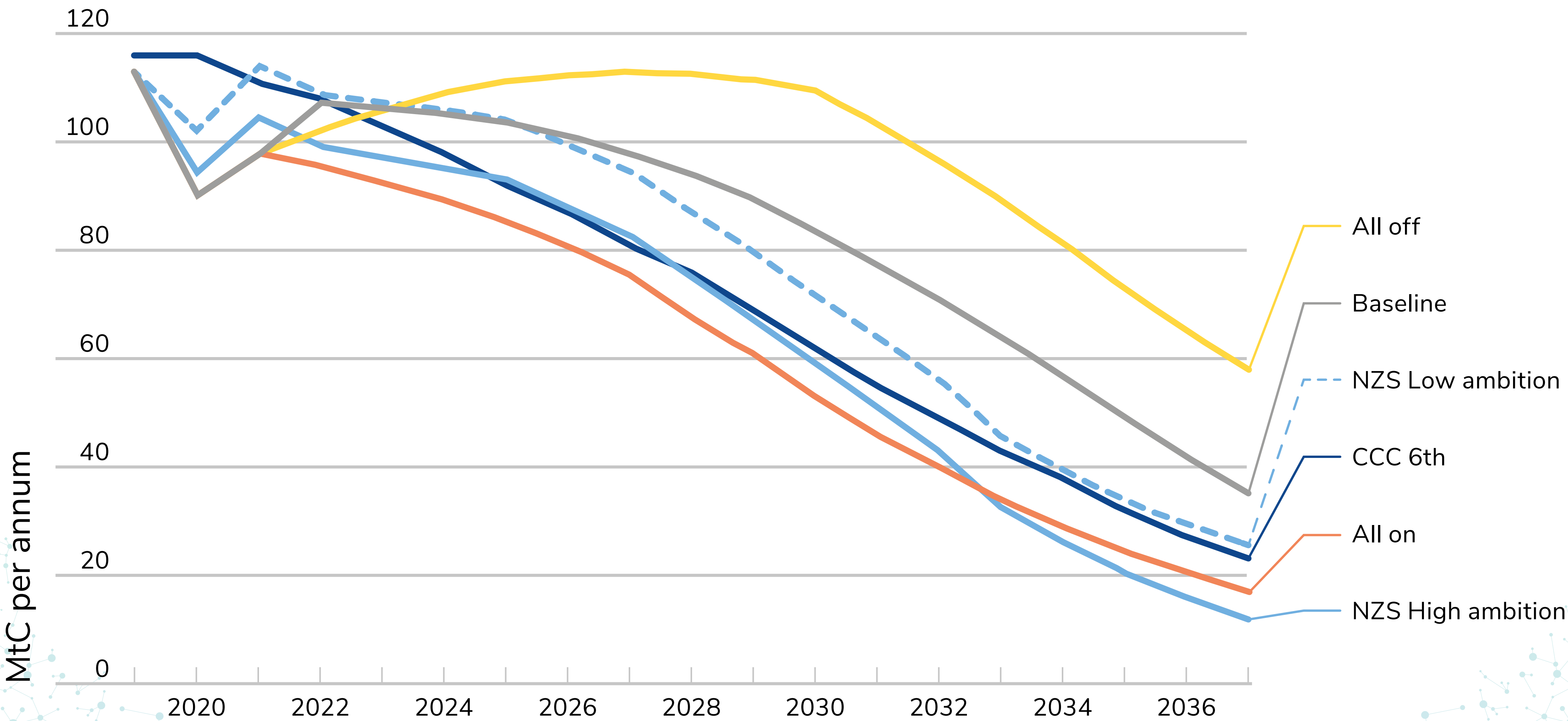


Fig. 15: Predicted (left) and actual (right) cars per LSOA (2011)
Dixon, J. et al. 2021, *Future Transportation* 1.
https://doi.org/10.3390/futuretransp1010008

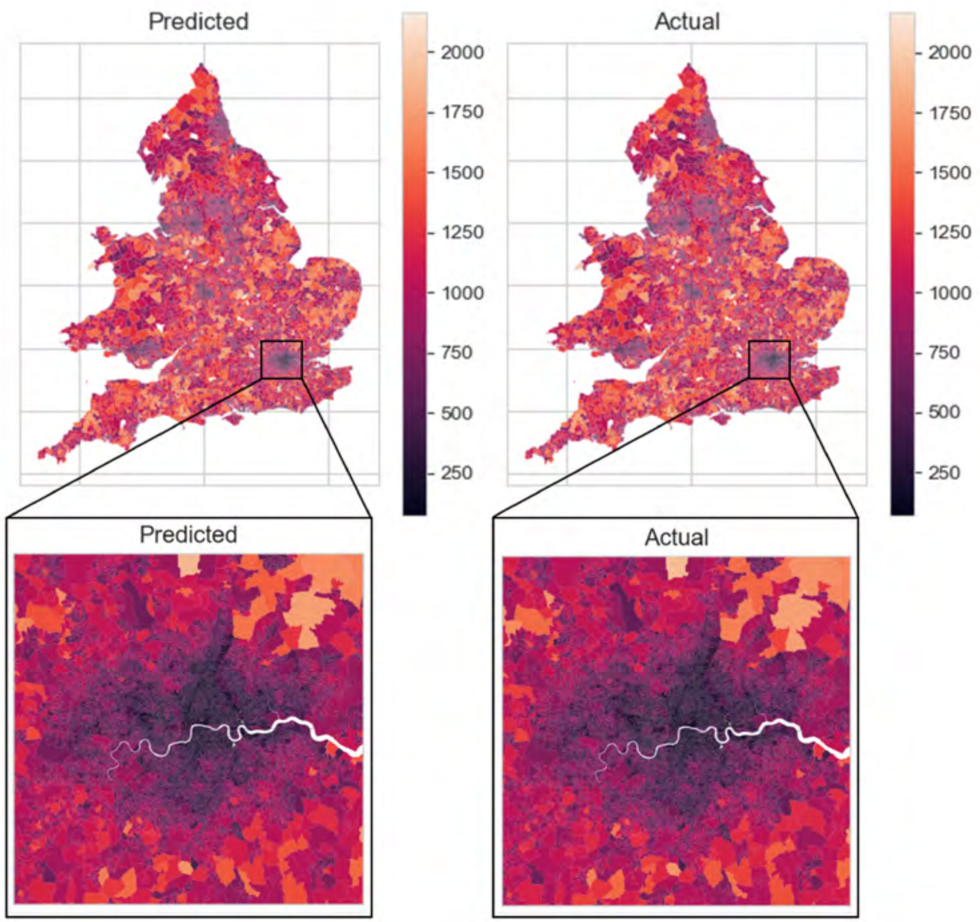


Fig. 16: Predicted (left) and actual (right) change in cars (2001–2011) per LSOA
Dixon, J. et al. 2021, *Future Transportation* 1.
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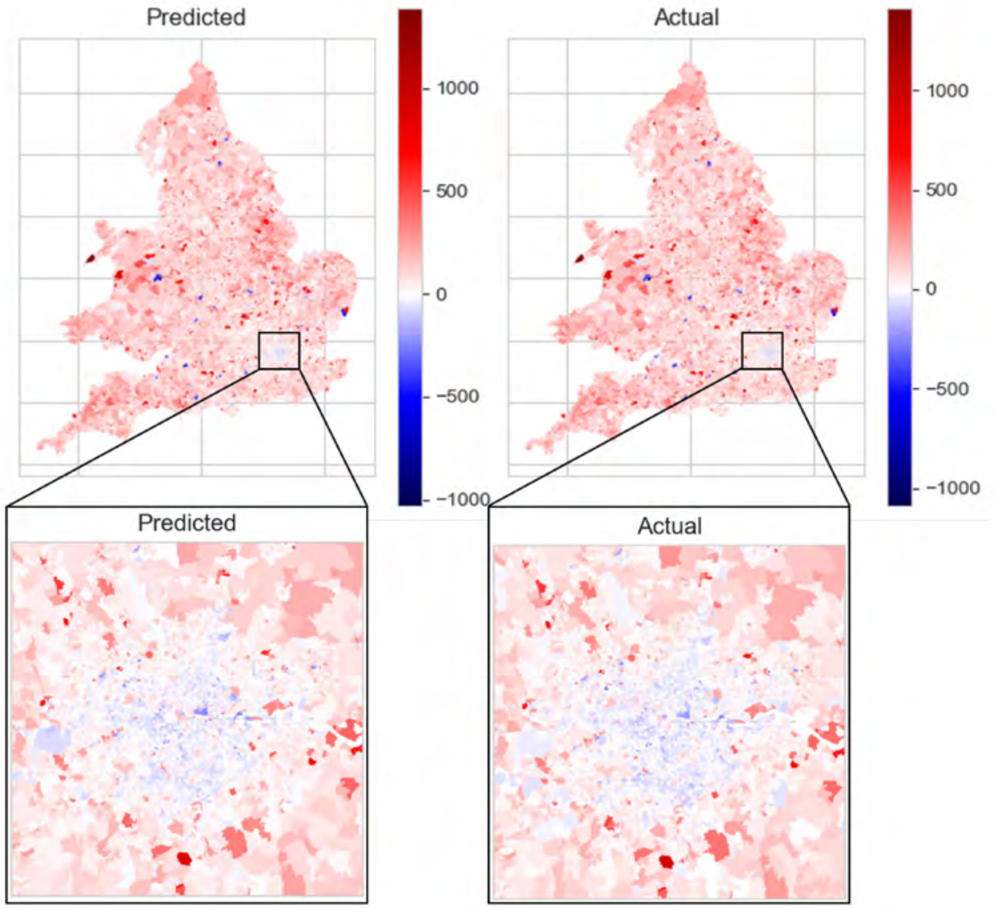


Fig. 17: CO_2e emissions for passenger cars (left panel) and vans (right panel) for an ambitious ICT/eco-driving future
Tran, M. and Brand, C. 2021, *Environ. Res. Lett.* 16. http://www.doi.org/10.1088/1748-9326/ac302e

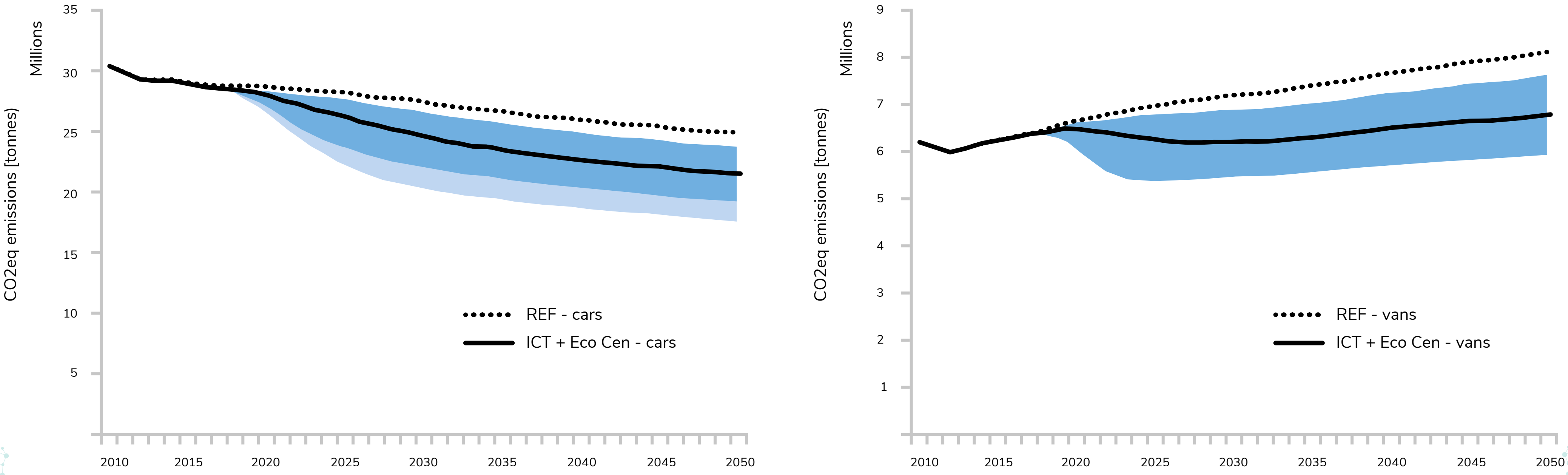


Fig. 18: Illustration of the 'superblocks' model of urban transport planning, as implemented in e.g. Barcelona
Mueller, N. *et al.* 2020, *Environ. Int.*134. https://doi.org/10.1016/j.envint.2019.105132

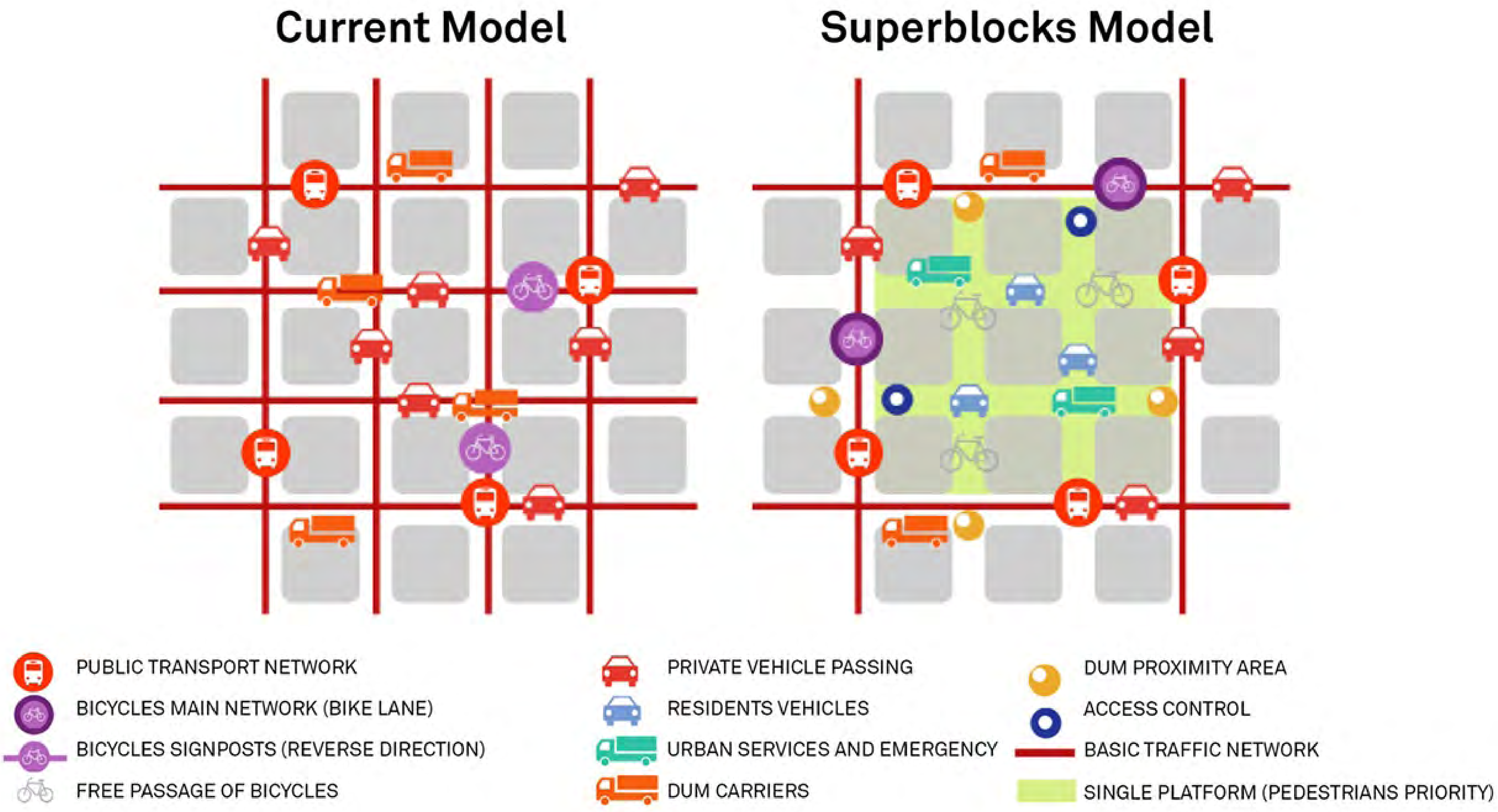


Fig. 19: Change in NO_2 and $PM_{2.5}$ concentrations in 2040, the CCC's 'Widespread Innovation' scenario
Assareh, N. et *al.* 2025, *Environ. Sci. Technol.* 59. https://doi.org/10.1021/acs.est.4c05601

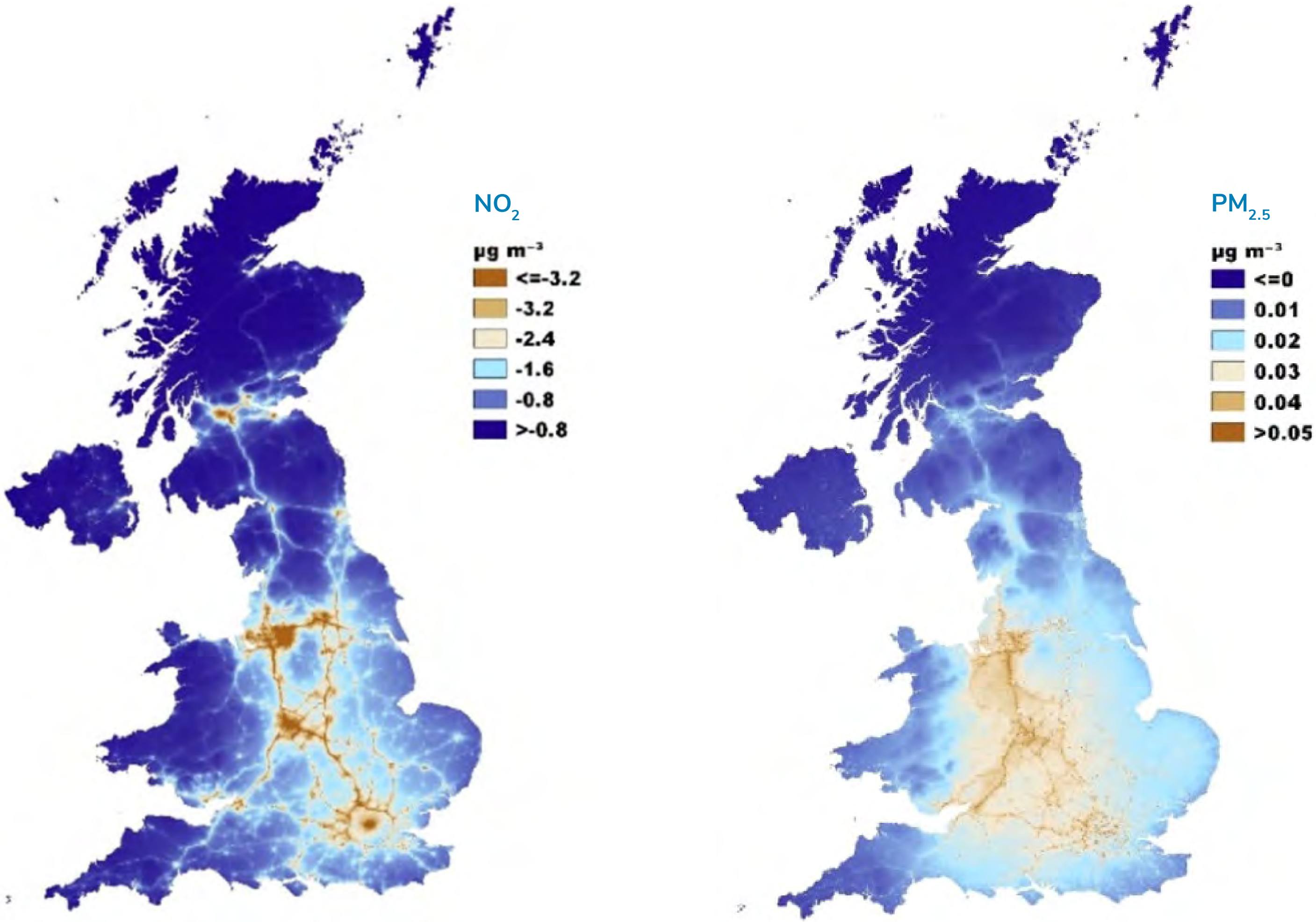


Fig. 20: Health and associated economic benefits of reduced air pollution and increased physical activity from climate change policies
Walton, H. et *al.* 2025, *Environ. Int.* 196. https://doi.org/10.1016/j.envint.2025.109283

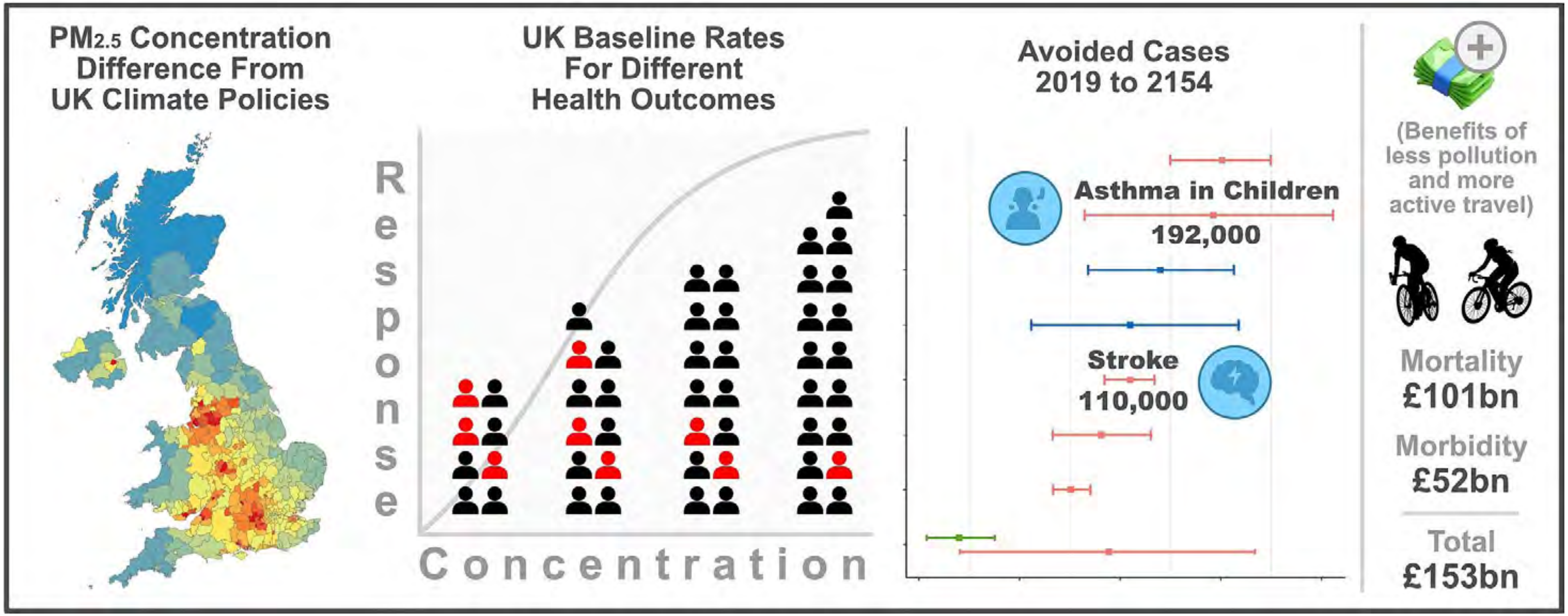


Fig. 21: Net economic benefits for the transport sector under the BNZP scenario
Beevers S. *et al.* 2025, *Environ. Int.* 195. https://doi.org/10.1016/j.envint.2024.109164

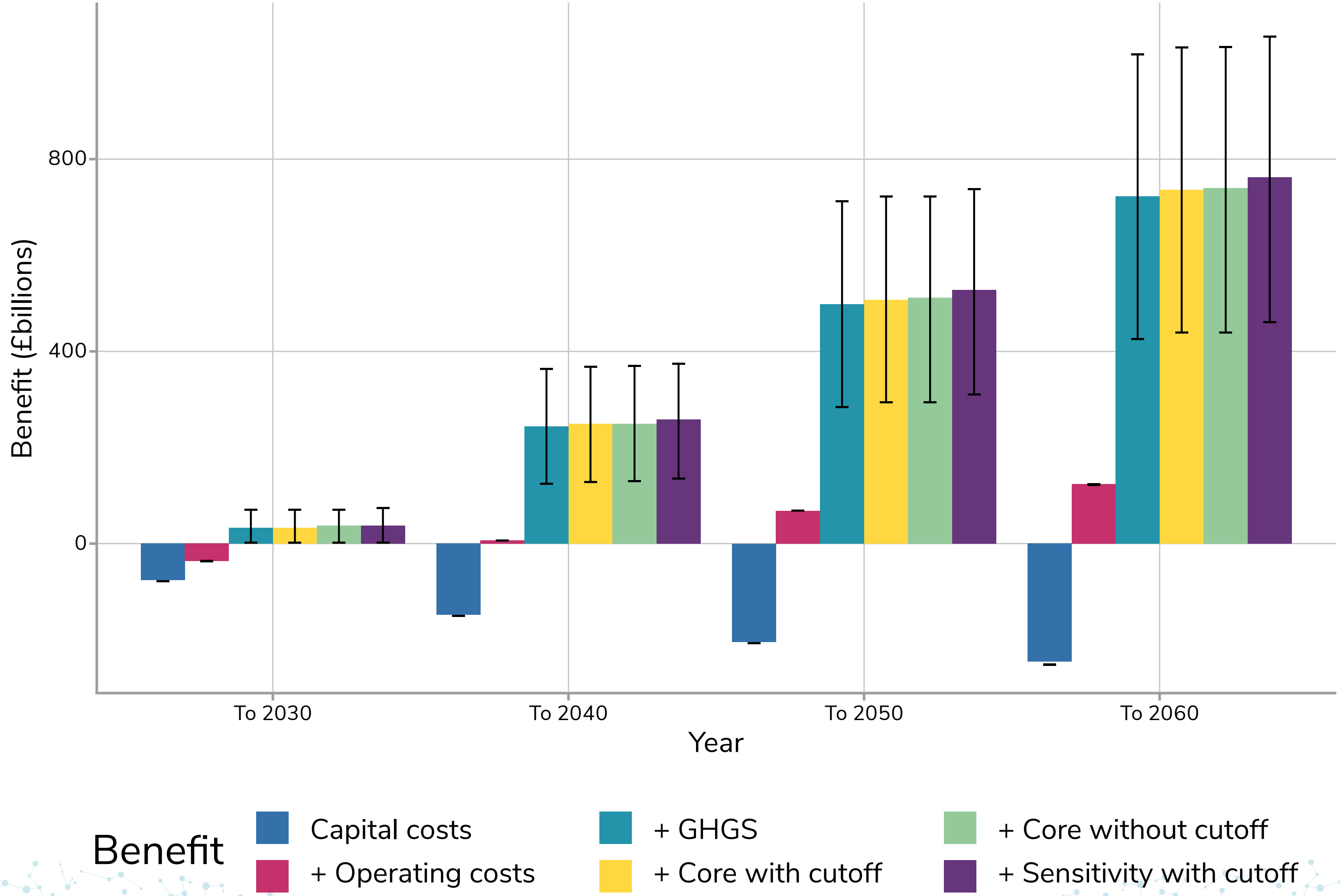
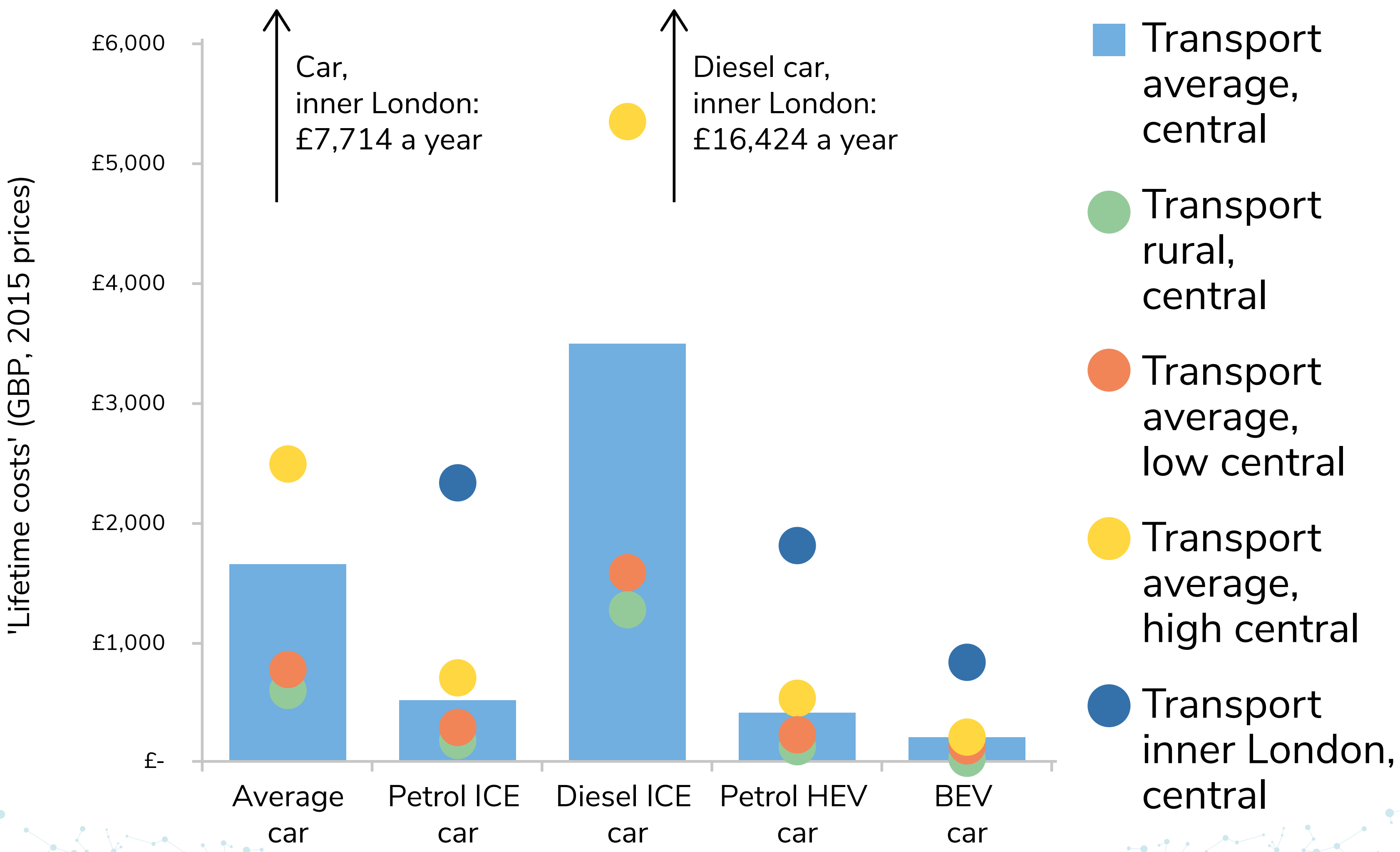


Fig. 22: Lifetime health damage costs of cars
Brand, C. and Hunt, A. 2018, Global Action Plan. https://ukerc.ac.uk/news/clean-air-day-2018/



Transport Evidence Compendium

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