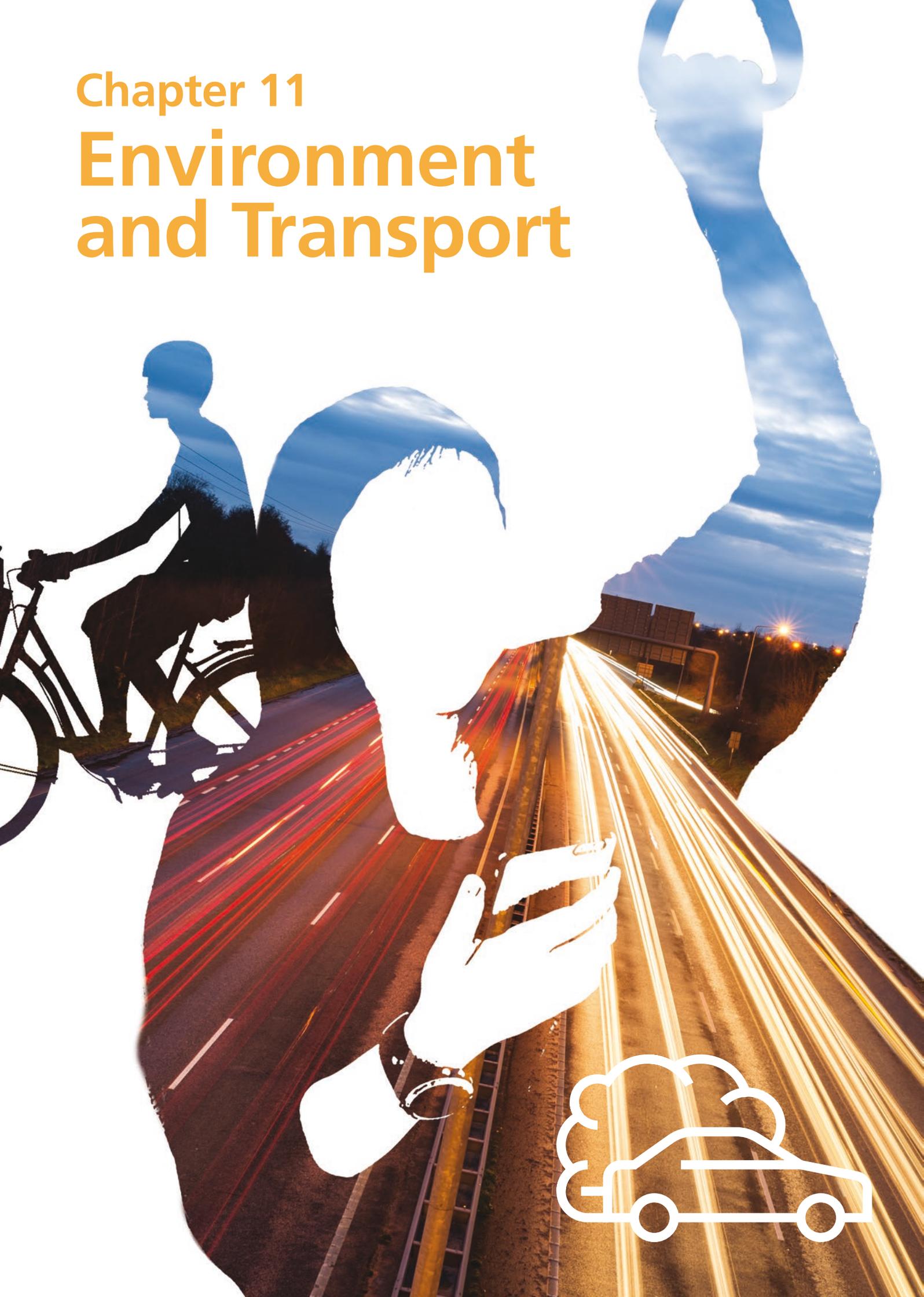


## Chapter 11

# Environment and Transport





# Environment and Transport

## 1. Introduction

Transport systems provide connectivity for delivering the goods, services, amenities and employment that underpin human wellbeing. A sustainable, accessible and efficient transport system is not only important for welfare but has a key function in trade and the economy. It also facilitates tourism and is an employer and source of government revenue in itself. Yet transport is also a major consumer of energy and material resources, and a key source of environmental pressures in Ireland, particularly of greenhouse gases, air pollutants and noise. It takes up large swathes of land and contributes to urban sprawl, the fragmentation of habitats and the sealing of surfaces (EEA, 2019a). Reducing the impact of transport systems is one of the biggest challenges to delivering a sustainable and low-carbon economy and society. The European Environment Agency (EEA), in its state of the environment report 2020, highlighted transport and mobility systems as particularly damaging to the environment. The EEA reported that transport is one of the key sectoral areas where system change is needed (EEA, 2019a).

Designing a sustainable transport and mobility system needs a managed policy-driven transformation, a path in which the driving forces behind the environmental pressures are avoided, shifted and improved. The current path presents great challenges, with increased travel demand, congestion and environmental pressures, affecting quality of life, economic competitiveness and the environment. Continuing on this path risks deepening lock-in of undesirable outcomes long into the future. This chapter explores the environmental pressures, their underlying driving forces and the responses required to move on to a path of sustainability in the transport sector. A sustainable path is characterised not only by lower environmental pressures, but also by win-win outcomes, for human health and wellbeing, for cleaner and quieter town and city centres, and for the economy.

## 2. Environmental Pressures from Transport

### Energy Consumption

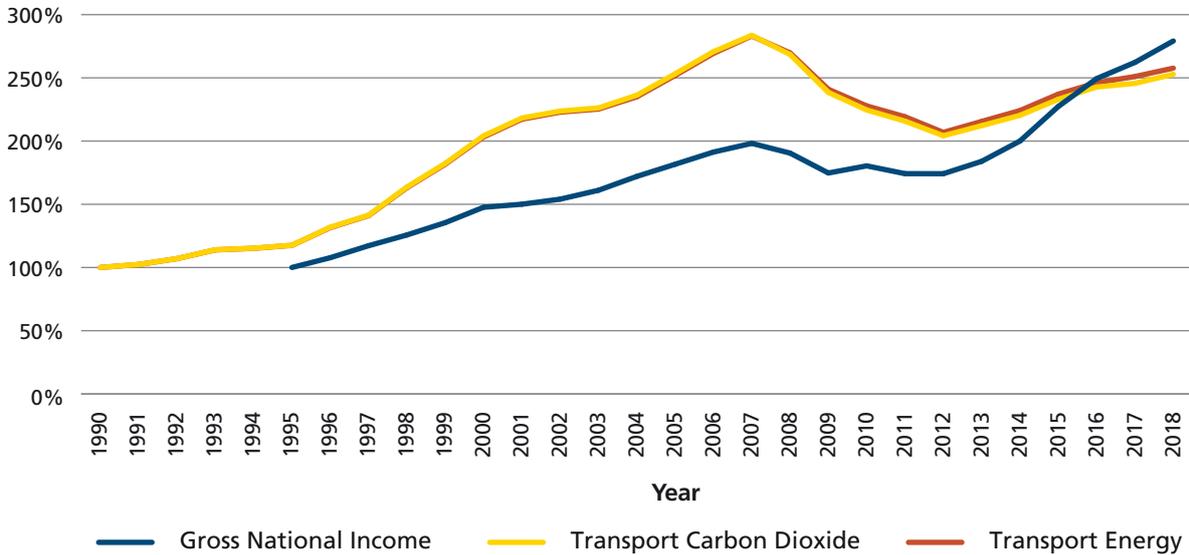
**Transport is the largest energy-consuming sector in Ireland, with a 42 per cent share of final consumption, most of which is imported oil.**

Consumption of energy has been strongly driven by economic and population growth, but also by decades of public and private choices that affect the transport system. Figure 11.1 shows that growth in energy consumption exceeded that of the economy until 2007. This was followed by continual declines until 2012, and a resumption as the economy recovered. Consumption in 2018 was 25 per cent higher than in 2012, having increased every year since then. Aviation alone grew by 7.9 per cent in 2018, accounting for 21 per cent of energy used for transport, second only to private cars, and more than heavy and light goods vehicles combined (SEAI, 2019a). The continuing growth in transport energy consumption is a major concern for the two headline environmental pressures that arise from transport: greenhouse gas emissions and air pollution. Figure 11.1 shows that increases in energy consumption have driven near-linear increases in transport carbon dioxide emissions, despite increased electrification and biofuels.





**Figure 11.1** Trends in transport carbon dioxide emissions, energy by final consumption and in the economy by gross national income at constant market prices (Source: SEAI 2019b and CSO 2019a)



### Greenhouse Gas Emissions

While transport is a key sector globally for the reduction of greenhouse gas emissions, the scale of the challenge is even more pronounced in Ireland.

Table 11.1 shows that in 2018 Ireland's transport emissions per capita were the fourth highest in the EU-27, and well above the average. EPA data show that transport is Ireland's second largest emitter, behind agriculture, at 20.3 per cent of the national total emissions, or 12.2 million tonnes of carbon dioxide equivalent in 2019 (EPA, 2020f). Even though these data exclude international aviation, consistent with international reporting convention, emissions still grew by 137 per cent between 1990 and 2019. The urgency of addressing climate change led to the Paris Agreement of 2015, which aims to limit global temperature increases to well below 2°C and close to 1.5°C. Increasing national transport emissions contribute to the difficulty in meeting our emissions reduction targets, towards this ultimate goal. Excluding international flights, transport accounts for 27 per cent of the emissions that need to be reduced to meet emission reduction targets to 2020 and 2030. Continuing growth of emissions highlights the need for further progress and additional measures, such as those announced in the 2019 Climate Action Plan, to achieve a long-term low-carbon climate-neutral economy. The stated ambition for climate neutrality by 2050 implies that Ireland will need to eliminate greenhouse gas emissions from land transport almost entirely by then.

**Table 11.1** Transport carbon dioxide emissions per capita, Rank in EU-27, 2018 (Sources: Crippa et al., 2019; Eurostat, 2020)

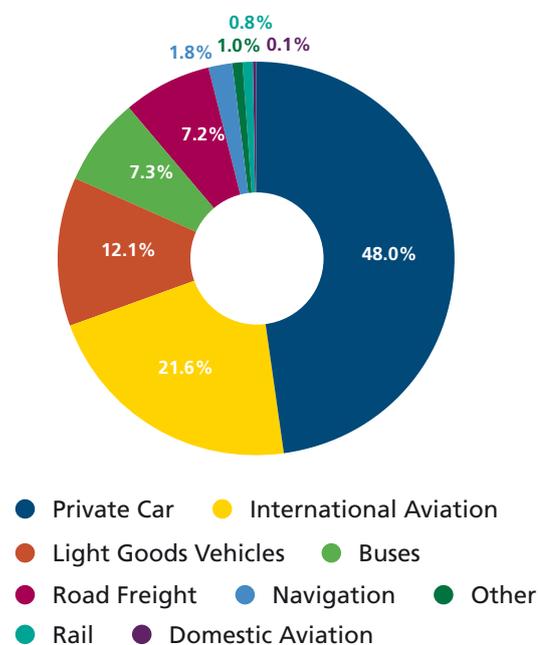
RANK	STATE	CARBON DIOXIDE PER CAPITA (TONNES)
1	Luxembourg	10.23
2	Austria	2.77
3	Slovenia	2.76
4	Ireland	2.51
5	Belgium	2.31
–	EU average	1.80





The data illustrated in Figure 11.1 are for the total environmental pressure of all carbon dioxide emissions from transport (SEAI, 2019b). This highlights growth of 158 per cent between 1990 and 2018, when international flights and transport electricity are included. Figure 11.2, breaks down the latest EPA Provisional Greenhouse gas Inventory data to show the emissions from different Transport modes that dominated in 2019. The private car was the largest contributor, at 48 per cent, followed by international aviation, at 22 per cent, and road freight (trucks), at 7 per cent. The remaining emissions are predominantly from light goods vehicles (vans) and buses. Since 1990, carbon dioxide emissions from the private car fleet have grown by 139 per cent, from international flights by 209 per cent and from road freight by 104 per cent. These patterns show how choices have led to transport becoming more individualised and motorised, driving up emissions, with a shift in freight away from the more sustainable mode of rail (O'Mahony *et al.*, 2012). Recently, the National Travel Survey suggests that there has been little shift to walking, cycling, rail and bus, with a slight decline noted from 2013 to 2019 (CSO, 2020a) (Passenger Transport section in 3. Understanding the Drivers of Transport Environmental Pressures). The place of international flights in policy to reduce emissions is discussed in Topic Box 11.1.

**Figure 11.2** Shares of Irish carbon dioxide emissions by mode of transport, 2019  
(Source: EPA, 2020f)



### Topic Box 11.1 International Flights and Reducing Greenhouse Gas Emissions

Greenhouse gas emissions from international flights are a growing problem globally and are particularly high in Ireland. Irish per capita emissions, at 0.64 tonnes of carbon dioxide equivalent per capita, were the fifth highest in the European Union in 2017 (EEA, 2020a) and more than 20 per cent higher than our neighbour the United Kingdom.

The Chicago Convention of 1944 is the key international framework, which set principles for air transport, including the tax exemptions on aviation fuel. The 1997 Kyoto Protocol directed wealthier countries to pursue emissions reductions through the International Civil Aviation Organization (ICAO), with shipping also treated on a global basis. In 2010, the ICAO agreed aspirational goals to improve the fuel efficiency of international aviation by 2 per cent per annum until 2050, with the aim of keeping net emissions at the 2020 level. The ICAO's own analysis, however, showed that emissions continued to grow. In response, it proposed a full transition to biofuels and improved efficiencies by 2050.



Since 2012, the EU, which accounts for 35 per cent of global aviation emissions, has included the aviation sector in the Emissions Trading System. Flights to and from countries outside the European Economic Area are excluded, to facilitate development of a new global agreement. In 2016, the ICAO adopted the Carbon Offsets and Reduction Scheme in International Aviation (CORSIA), which comes into effect with a voluntary phase in 2021. The overall CORSIA target remains keeping net emissions at the 2020 level, but with a different approach whereby airlines are required to buy emissions reduction credits from other sectors to compensate for any increased activity, or use lower carbon fuels.



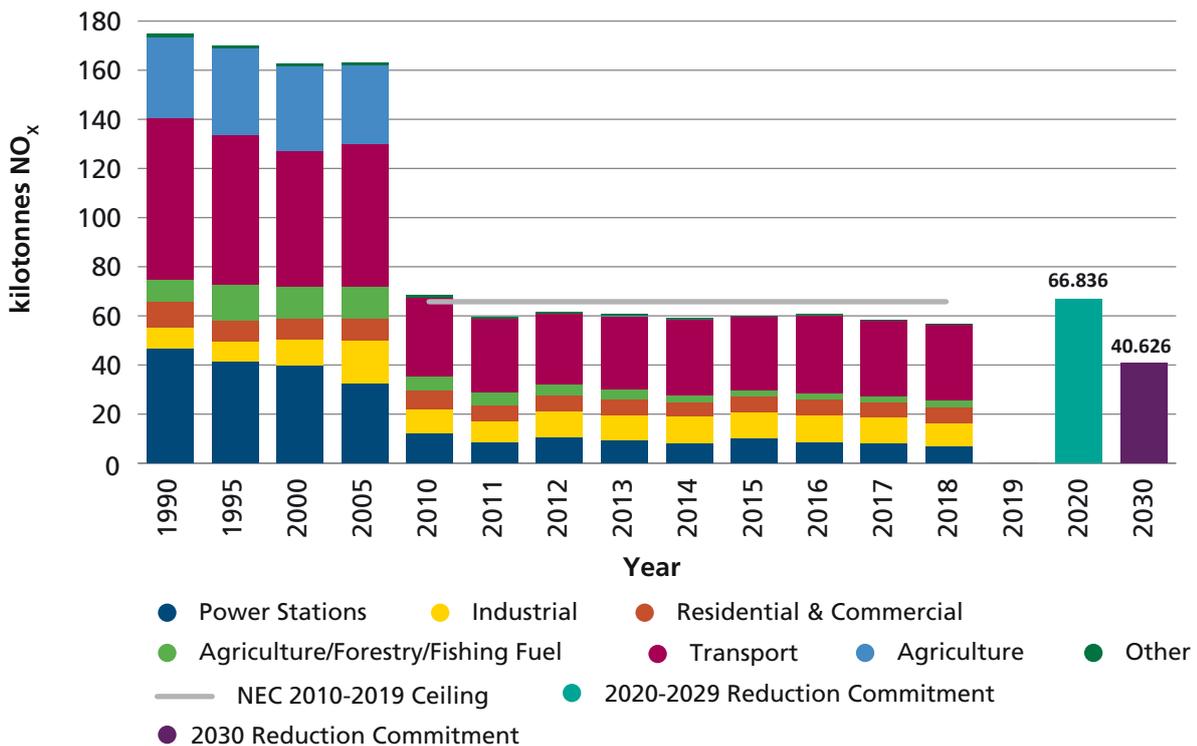
### Emissions of Air Pollutants from Transport Sources

Transport is a major source of air emissions and air pollution, arising primarily from the burning of diesel and petrol in standard internal combustion engine vehicles.

The majority of the emissions to air from transport in Ireland arises from diesel and petrol consumption by private cars and heavy goods vehicles (trucks). This is similar to the main sources of carbon dioxide emissions, as shown in Figure 11.2. To protect the environment and human health from air pollution, the EU has implemented a regulatory framework, for all sectors of activity, in the National Emissions Ceilings Directive (2016/2284/EU). Ireland has targets to limit emissions of sulphur dioxide, nitrogen oxides (NO<sub>x</sub>), ammonia, non-methane volatile organic compounds (NMVOCs) and fine particulate matter (PM<sub>2.5</sub>). In Ireland, transport is the principal source of NO<sub>x</sub> emissions, contributing approximately 41 per cent of the total in 2018, and a smaller contributor to sulphur dioxide, ammonia, NMVOCs and PM<sub>2.5</sub> (EPA, 2020b). NO<sub>x</sub> emissions are projected by the EPA to achieve compliance with the Directive in 2030, provided that the measures announced in the Climate Action Plan (including significant electrification of the transport sector) are implemented in full (EPA, 2020b). Figure 11.3 highlights the historical and projected future trends in NO<sub>x</sub> emissions in Ireland.

In the last three decades the general trend has been downward for a number of key air pollutants from transport, in contrast to the upward trend in CO<sub>2</sub> emissions in the same period. These patterns are common across the EU, as air pollution targets are tightened in all Member States. Technological improvements that were expected to be effective in reducing air pollution, through EU fuel quality and vehicle emissions standards, have not delivered the projected pollutant reductions for nitrogen dioxide and have also not delivered for carbon dioxide. It is hoped that the introduction of newer passenger vehicles, that meet the Euro 6D-TEMP and follow-on standards, will contribute to improvement in some pollutants. In Ireland, the replacement of vehicles with newer, more efficient models has also contributed; a useful co-benefit of policy for energy and carbon efficiency. However, recent increases in the size of the national vehicle fleet and moves towards diesel engines have limited further improvement (EPA, 2020b). Industry data also appear to show an increasing dominance of the more energy- and carbon-intensive sport utility vehicle (SUV) market segment, at 39.4 per cent of registrations in 2019 and increasing (SIMI, 2020).

**Figure 11.3** Trend in NO<sub>x</sub> emissions 1990-2030, current and future emission ceilings (Source: EPA, 2020b)



Note: Article 4(3) of the National Emissions Ceilings Directive provides that emissions of NO<sub>x</sub> and NMVOCs from categories 3B (manure management) and 3D (agricultural soils) are not counted for the purpose of complying with 2020 and 2030 ceilings.



## Impacts of Air Pollutants on the Quality of Air We Breathe

Air pollutants have damaging effects on the environment and human health.

The impact of air pollutants on health and the environment is covered in more detail in Chapter 3 and Chapter 14. The major pollutants of concern from transport are nitrogen dioxide and particulate matter; transport is the main source of nitrogen dioxide.

Nitrogen dioxide can become particularly troublesome where pollution becomes concentrated, in urban areas and near transport networks, and for those with vulnerable health status. The EPA monitors a range of other air pollutants in line with the EU air quality directives. In its annual Air Quality in Ireland reports, the EPA compares Irish air quality both with EU legal limit values and with World Health Organization guideline values. In Ireland, road transport is the largest source of carbon monoxide, copper, zinc and black carbon emissions. It is also a significant source of coarse particulate matter (PM<sub>10</sub>), lead, mercury and chromium emissions. The EPA's most recent Air Quality in Ireland report highlighted an exceedance of the EU annual average legal limit values in 2019 at one urban traffic station in Dublin, due to pollution from transport (EPA, 2020e).

Public concern about the negative impacts of air pollution from transport is rising (EEA, 2019b), with poor air quality linked to serious health implications, both short term (acute temporary complaints such as headache, breathing difficulty or eye irritation) and long term (chronic ongoing conditions including asthma, reduced liver function and cardiovascular disease) (EPA, 2019). Ever-expanding research is demonstrating links to even wider impacts on human health such as on cognitive development (Zhang *et al.*, 2018) and mental health (Braithwaite *et al.*, 2019). Recent Irish research has shown the negative health impacts on the Irish public (Carthy *et al.*, 2020; Quintyne *et al.*, 2020).

This is particularly important for more vulnerable groups such as children and pregnant women. Recognising the considerable impact of transport air pollution on human health and ecosystems, while some progress has been made, the European Environment Agency notes that its continuing contribution to poor air quality requires systemic changes in how we transport people and goods, rather than relying on efficiency measures alone (EEA, 2019a).

## Noise

Noise from transport networks is the most widespread source of environmental noise exposure in Ireland.

In 2018, the World Health Organization (WHO) published *Environmental Noise Guidelines for the European Region* (WHO, 2018). This established how noise pollution in our towns and cities is increasing, and how excessive noise particularly from transport sources is a health risk, with effects on sleep, cardiovascular and metabolic function, in addition to the nuisance caused. In Ireland, the expansion of the national road infrastructure has led to increased transport activity, and thus continuing this pattern is likely to lead to increasing noise exposure. Noise modelling carried out in Ireland during 2017 estimates that 15.6 per cent of the population are exposed to noise levels above 55 dB L<sub>den'</sub>, with more than 90 per cent of this exposure attributable to road traffic noise (EEA, 2019a). The WHO has recommended daytime noise levels from road traffic of 53 dB L<sub>den'</sub> and night-time levels of 45 dB L<sub>night</sub> as the thresholds above which adverse health effects can start to occur, (WHO, 2018). A transport system that promotes increased road usage, and the private car in particular, is likely to lead to increasing noise exposure levels, even with a larger numbers of electric vehicles. Technical measures for reduction of noise exposure have their limitations, so reducing demand and encouraging major modal shifts to walking, cycling and public transport should be the long-term goal. It will also be important as we move to more integrated spatial and transport planning, that 'quiet areas' continue to be protected (see Chapter 4 for more details).

## Other Environmental Pressures

Transport sources drive a range of other environmental impacts.

Road transport expansion is associated with urban sprawl. The related land-take and habitat fragmentation have impacts on biodiversity, ecosystem services and habitat resilience. The sealing of surfaces can increase run-off during high-precipitation events. There are also growing adaptation challenges for management of the impacts of climate disruption. In recent years, both central and local governments have begun building resilience to climate change through transport adaptation planning. EPA research in the Methodologies for Financing and Costing of Climate Impacts and Future Adaptation Actions (TACT) project<sup>1</sup> considers the potential vulnerability of national transport infrastructure to increasing extreme weather events. Management of environmental pressures by local authorities and state agencies is necessary, but, in addition to this environmental protection, there is also a pressing need for integrated strategic long-term policy at the national level, to prevent and minimise the variety of environmental pressures.

<sup>1</sup> The project, funded by the EPA, ran from 2018 until 2020. See <http://erc.epa.ie/smartsimple/displayProject.php?projectCode=2018-CCRP-DS.13>.



### 3. Understanding the Drivers of Transport Environmental Pressures

#### Passenger Transport

Key sectoral indicators are pointing in the wrong direction at the national level.

Analysis can help to understand the driving forces of environmental pressures and can support the development of evidence-based policymaking that considers the full range of policy solutions available. The Intergovernmental Panel on Climate Change (IPCC) considers drivers such as demand, infrastructure, technology, and the public policy, private market and lifestyle factors that underlie these (Sims *et al.*, 2014).

While transport greenhouse gas emissions are a challenge globally, Table 11.1 indicates that in Ireland this is more pronounced. In recent decades, alongside the push of economic and population growth, Ireland has experienced low-density and sprawl patterns of spatial development (EEA and FOEN, 2016; Ahrens and Lyons, 2019), and an infrastructure investment priority on road development and mobility dominated by private cars. All these factors are associated with higher levels of greenhouse gas emissions, and increased road congestion. They are represented in long-term trends towards more private and motorised transport, and at best marginal increases in the active modes of walking and cycling (CSO, 2020a). In contrast to other European countries, a higher proportion of public transport is by bus than rail, and rural areas have limited access. While some progress has been made on key transport air pollutants, these drivers are of major concern regarding greenhouse gas emissions, noise, urban sprawl and land-take, and biodiversity. These patterns of development implicitly increase mobility demand and related emissions, and risk long-term 'lock-in' to unsustainable patterns that are difficult to escape (Seto *et al.*, 2016). More dispersed and sprawling development can imply private benefits, but these must be weighed against their societal environmental and economic costs, such as the cost of providing public services to lower density patterns (OECD, 2018).

The most recent National Travel Survey, of 2019, suggests that journey distances and durations have increased since the first national survey in 2012 (CSO, 2020a). In 2019, almost two-thirds (64.9%) of journeys were made as a driver of a private car, or 77.6 per cent by 'private motorised transport'<sup>2</sup>, with little shift to sustainable modes in recent years<sup>3</sup>. In addition, the survey

showed that 43.6 per cent of all journeys in 2019 were of shorter distances, less than 4 kilometres, which are ideal for active modes. Within this, 51.5 per cent of journeys of less than 2 kilometres were by car, rising to 66.1 per cent for journeys between 2 and 4 kilometres. Together, this suggests the potential for switching to active modes for shorter journeys, particularly when noting apparent gains in sustainable modes in some urban areas.



The impact of the reliance on private vehicle transport on greenhouse gas emissions is compounded by increasing journey lengths and the energy and carbon inefficiency of the vehicle choice. The total distance travelled by cars rose by more than 14 per cent between 2012 and 2018 (SEAI, 2019a). Gains from improvements in the energy efficiency of new private cars are also being overwhelmed as consumers favour larger, less efficient vehicles such as SUVs (SEAI, 2019a). Carbon efficiency has shown only minor improvement. Biofuels have increased to 3.9 per cent of road and rail transport energy consumption in 2018, from 2.4 per cent in 2010 (SEAI, 2019a), and 8,827 battery electric cars were licenced in Ireland between 2010 and 2019<sup>4</sup> (CSO, 2020b). While increasing, this remains a tiny fraction of the national car fleet, which stood at over 2.1 million vehicles licenced in 2018.

The problem of road traffic congestion is also of note here, as Irish cities frequently place high in global surveys. In the INRIX survey from 2018, Dublin ranked as the 15th most congested city, with Galway 50th, Limerick 72nd and Cork 80th (INRIX, 2018).<sup>5</sup> Congestion is known to have negative effects not just on the environment and economic competitiveness, but also on quality of life and human health, through concentration of air pollution, increased stress, obesity and lost time.

2 'Private motorised transport' is taken here as car drivers, car passengers, taxi/hackney, lorry, motorcycle and van. It excludes the new 'other' category of e-mobility at 0.7% in 2019, see CSO (2020a).

3 The 'sustainable modes,' defined here as walking, cycling and public transport, have declined by 1.2% from 2013 (22.8%) to 2019 (21.6%).

4 This is the number of new and used electric cars, not including other vehicle types. Over the same time period, 51,014 new and used hybrid cars, including petrol, diesel and plug-in options, were added to the fleet in Ireland. It is important to note, that in general, hybrid vehicles have less potential to eliminate carbon emissions than battery electric vehicles.

5 In the 2018 TomTom index, similar results are found: Dublin was ranked as the 14th most congested city in the world, with Cork at 70th and Limerick at 94th (TomTom, 2019).



## Freight Transport

**Improving the sustainability of freight requires achieving a modal shift to rail, yet Irish rail freight has seen decades of decline and freight activity has shifted in the opposite direction: to road.**

The emissions outcomes of freight depend on factors such as the level and type of economic activity, whether the mode used is road or rail, and the demand-side efficiency factors of capacity usage, logistics, vehicle type and fuel. Ireland experienced a significant growth in freight activity up to a peak in 2007, and this growth was particularly strong in the freight-intensive construction sector. The economic recession saw a major drop in activity from that seen during the house- and road-building boom. There has been an increase in freight activity since the recession, measured by tonne-kilometres, linked to the economic recovery. However, it remains 39 per cent below its peak in 2007 (SEAI, 2019a), owing to the reduced trade in construction materials.

A key plank of improving the sustainability of freight in the EU is achieving a modal shift to rail, yet Irish rail freight has seen decades of decline and a shift in the opposite direction: to road (O'Mahony *et al.*, 2012). Ireland now has the lowest proportion of rail freight in the EU-28, apart from Cyprus and Malta (McKinnon, 2019), pushing a shift towards the more energy- and emissions-intensive road modes. The energy efficiency of Irish road freight per tonne-kilometre is poor by international standards (SEAI, 2014), and does not appear to have improved since 2000. This suggests that factors such as logistics, matching vehicle to load and empty running are continuing to make freight more inefficient, as found in the previous analysis by O'Mahony *et al.* (2012). On the other hand, the carbon efficiency of road freight has changed only marginally, as biofuels now make up 4 per cent of energy consumed. Taken together, these factors have led to a continued increase in freight carbon dioxide emissions for the last 8 years. A discussion of decarbonisation of freight is included in Topic Box 11.2. The research study by Mulholland *et al.* (2020), for the EPA, discusses a variety of efficiency measures for transport decarbonisation and includes some logistical measures.

Declining rail freight volumes in Ireland have sometimes been attributed to short distances and economics, through lack of cost competitiveness with road freight. However, distance need not be a limiting factor according to Booz & Company (2009), which offered examples of short freight distances in Ireland that continued to be economically viable. The viability of these routes is perceived as coming about through innovative logistics solutions and cost reductions. It is also notable that other relatively small countries, such as Portugal and New Zealand, have proven more successful. An expansion of the rail freight logistics network could be developed

as part of a 2050+ rail vision, including rail heads, bypass lines, and consolidation and distribution services at stations. It is plausible that providing the required systems and infrastructure, and internalising the societal costs of roads (such as road traffic accidents, congestion, emissions, noise and habitat fragmentation) in transport pricing, could alter the economics to favour rail.

Road modes almost exclusively generate the external societal costs of transport in the EU (Directorate-General for Mobility and Transport, 2019a). Owing to the relatively high costs of accidents and congestion of road freight, EU average external costs of heavy goods vehicles (€0.042 per tonne-kilometre), are more than three times as high as those of rail freight (€0.013 per tonne-kilometre). Passenger transport shows an even greater difference, with average external costs of the private car (€0.120 per passenger-kilometre) more than four times as high as rail (€0.028 per passenger-kilometre), and electrified rail cheaper still.

Light goods vehicles are a significant source of emissions (Figure 11.2), almost half as much as heavy goods vehicles. They have been separated in the data only since 2014, and increases may be attributed to factors such as increased carriage of goods and just-in-time deliveries. The EEA has suggested that there is scope for a reduction in light vehicle trips through providing a service that facilitates consolidation of small shipments (EEA, 2020b). This could be combined with new facilities at rail stations to enhance the feasibility of switching freight to rail in the long term.

### Topic Box 11.2 Five decarbonisation initiatives for freight transition

The global freight expert, and IPCC lead author on transport, Professor Alan McKinnon, discussed freight transition at the Climate Change Advisory Council's 2019 workshop on 'Transition of Irish Transport: Issues, Approaches and Options' (McKinnon, 2019).

McKinnon (2018) applies the avoid-shift-improve (ASI) framework to future freight transition, through a hierarchy of five decarbonisation initiatives: demand management; shifting to lower intensity modes; logistics and vehicle loading; improving energy efficiency; and reducing carbon intensity by using electric vehicles, compressed natural gas vehicles, etc. He outlines a plethora of advanced future-proofed levers and options at each level and considers implications. McKinnon concludes that meeting an 80 per cent greenhouse gas reduction target by 2050 may not be possible without demand management, and notes that freight shift to rail is ideal. He also discusses the unique needs of freight, as distinct from passenger transport, which often are not sufficiently separated.



## Projections and Policies

Reducing greenhouse gas emissions and making transport in Ireland sustainable require the implementation of fundamental and significant policy changes.

As outlined in Chapter 2, the EPA has projected under its 'with additional measures' scenario that transport greenhouse gas emissions will peak at 12.4 million tonnes of carbon dioxide equivalent in 2020. Table 11.2 illustrates a decline to 4.4 million tonnes in 2040, if the measures announced in the 2019 Climate Action Plan are fully implemented (EPA, 2020c). This projection involves a set of economic assumptions about how oil price affects energy demand, and the successful completion of all policies and measures in place at the time of the study. The EPA 'with additional measures' projection of 2020 foresees an average annual reduction in transport greenhouse gas emissions of 4.7 per cent per year to 2040. Assuming a drop in transport emissions by 80 per cent of 1990 levels by 2050 would require an average reduction of 4.2 per cent per year, indicating that the decarbonisation measures in the Climate Action Plan can be effective if fully and successfully implemented.

Work on the latest EPA emissions projections started in late 2019 and they are underpinned by strong projected growth in key sectors of the economy. The impact of the coronavirus pandemic (COVID-19) is not included in these figures; for 2020, and probably for some time thereafter, it is expected that there will be a downward impact on both greenhouse gas and air pollutant emissions, particularly NO<sub>x</sub> emissions. In April 2020 alone, petrol deliveries were over 72.5 per cent lower than in April 2019 and diesel deliveries almost 55.5 per cent lower (CSO, 2020c). As a result of reduced traffic, the EPA observed some significant decreases in the concentrations of nitrogen dioxide at urban traffic stations, with decreases of up to 50 per cent compared with the January average (EPA, 2020d).

Staying at home and staying local reduce travel demand, benefiting air quality and helping to tackle climate change. In exiting from pandemic measures, it is important to be aware that the recovery steps will shape Ireland for decades, as is known to occur with major policy developments. Such junctures offer the opportunity to focus on climate action measures, as part of a green recovery stimulus, to rebuild our economy, generate new jobs and respond to climate change.

Recognising that the emissions reductions required of transport are set to deepen, the national Climate Action Plan (Government of Ireland, 2019) established a number of new measures to meet the 2030 greenhouse gas targets for transport, while noting relevant measures already implemented. Five core areas can be highlighted from the Climate Action Plan: (i) compact development in spatial planning, (ii) shift to active and public transport, (iii) the carbon tax, (iv) biofuels and compressed natural gas and (v) electric vehicles. International evidence, including that from the IPCC, shows that:

- Spatial planning for compact development, to avoid trips and minimise distances, can deliver significant emissions reductions (Sims *et al.*, 2014). Ireland's National Planning Framework (NPF) aims for 40 per cent of future housing development to be within or close to the existing footprint of built-up areas (Government of Ireland, 2018). The balance is envisaged on a mix of sites, extending urban areas on sustainable transport corridors, and regeneration and renewal of rural towns and villages to arrest the decline of rural communities. This will be implemented through housing planning, local authority development plans and regional spatial and economic strategies, with independent scrutiny from the Office of the Planning Regulator. Local government will therefore play a key role in determining the actual outcome, in the mix of compact and dispersed development that arises.

**Table 11.2** EPA 'with additional measures' projection for Transport to 2040 Source: EPA (2020c)

	1990	2005	2016	2018	2020	2030	2040
Greenhouse Gas Emissions (in million tonnes CO <sub>2</sub> eq)	5.2	13.1	12.3	12.2	12.4	7.6	4.4



- The plan notes an existing target for the addition of 500,000 active and public transport journeys<sup>6</sup> per day by 2035, and supporting projects.<sup>7</sup> Evidence is not available to determine whether reaching this journey target will accommodate growing demand or lead to an actual modal shift from private car. Pathways that pursue substantial modal shift are typically based on longer term transformation of transport systems and infrastructure (Sims *et al.*, 2014).
- International evidence suggests that carbon taxes can complement regulatory measures, as part of an appropriate policy mix, but also have limitations, as passenger demand is 'inelastic' (Sims *et al.*, 2014).
- Improving carbon efficiency, through raising biofuel blend rates to 10-12 per cent of petrol and diesel, can be effective, but has historically been subject to sustainability challenges (CCAC, 2019a). Compressed natural gas for road freight provides a marginal improvement on life-cycle greenhouse gas emissions (Sims *et al.*, 2014).
- The flagship measure in the plan, to increase electric vehicle numbers to 936,000, would require diffusion rates similar to those achieved in the world leader, Norway.<sup>8</sup> Although the latest EPA projections indicate that this measure, if successfully achieved in full, can significantly reduce both air pollutant and greenhouse gas emissions from transport, it is important that it be accompanied by measures to reduce demand and shift travel to active and public transport modes. Otherwise we may tackle the climate challenge by achieving 'greener congestion' with attendant long-term economic, health and wellbeing impacts.



International evidence shows that some transport environmental pressures have been successfully addressed through environmental management, and that technical improvements can reduce some forms of air pollution. However, it also clearly shows that marginal and incremental efficiency is not sufficient to reduce transport greenhouse gas emissions, while also meeting the multiple social and economic objectives of transport. Delivering on this requires a 'sustainable mobility transformation'.



6 Total public transport journeys in 2017 were 300.8 million (CSO, 2019b).

7 Projects include the National Transport Authority 2035 Strategy with MetroLink, the Dublin Area Rapid Transit (DART) Expansion Programme, BusConnects and the addition of 200 kilometres of segregated cycle lanes.

8 Increasing the number of electric vehicles, to 936,000 by 2030, is approximately one third of the current national fleet of 2.7 million in 2018. Important to considering the feasibility of reducing emissions is the proportion of the future fleet this may involve. This is not clear from the target. It is worth noting, that in the case of Norway, achieving such rates of diffusion required significant state supports.



## 4. Sustainable Mobility Transformation

### Framing and Thinking

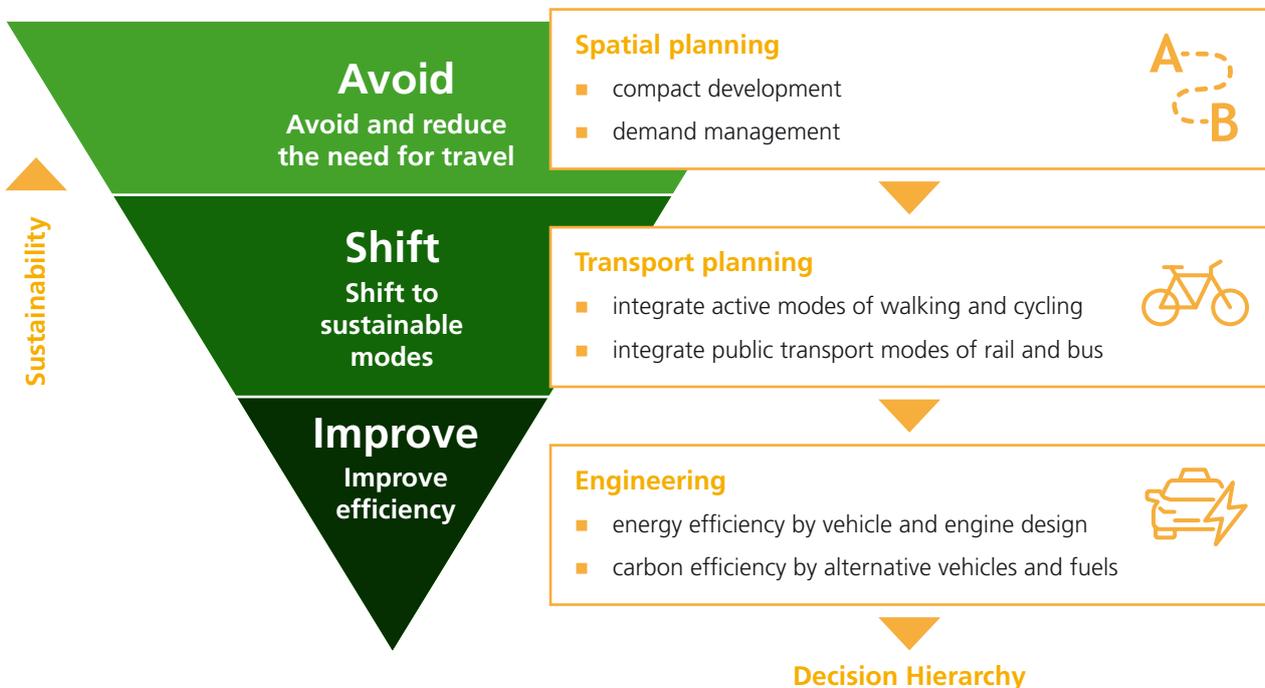
The new framing is represented in transport by moves from the low-carbon approach to the comprehensive sustainability approach in the ASI framework: avoid-shift-improve.

A fundamental change has occurred in the framing of and thinking on climate policy globally. This has evolved from focusing on short-term mitigation, by technical efficiency, to long-term transition and transformation, by systemic and structural change. Achieving sustainable mobility requires a similar transformation, along with the wider organisational and policy systems that the transport sector depends on, notably integrated spatial and transport planning.

The IPCC has noted the rise in global transport greenhouse gas emissions, despite efficiency, as transport activity has increased, while becoming more individual and motorised. The new framing is represented in transport by moves from the low-carbon approach to the comprehensive sustainability approach in the ASI framework (Devaney and Torney, 2019). This approach involves moving through a hierarchy of actions: *avoid* – avoiding journeys where possible, through innovative spatial planning, compact development and demand management; *shift* – shifting mode to the more sustainable modes of walking, cycling and public transport; and lastly *improve* – improving the energy and carbon efficiency of vehicles, including improved designs, choosing smaller vehicles, and switching to alternative powertrains and renewable fuels.

This hierarchy is illustrated in Figure 11.4. The approach is now a standard,<sup>9</sup> and is recognised by the IPCC, the EEA and the Organisation for Economic Cooperation and Development's International Transport Forum. More recently, in the Irish context, it has been recognised by the Climate Change Advisory Council (CCAC, 2019a) and the National Economic and Social Council (Devaney and Torney, 2019).

**Figure 11.4** The hierarchy of transport sustainability in the *avoid-shift-improve* framework (Source: EPA, adapted from EEA, 2016)



<sup>9</sup> Behavioural and social practice-based measures can be used to support 'avoid' demand management, and to encourage mode 'shift', where supporting systems and infrastructure are made available. Such measures can also be employed at the level of 'improve', to influence factors such as vehicle purchase and driving style.



The Department for Transport, Tourism and Sport has also acknowledged that the ASI framework is the best practice approach (DTTAS, 2019a). Building on this consensus, the next steps required are to:

- ensure that appropriate evidence is made available to inform decision-making at each level
- design policies and measures that can deliver effectively on each level and
- apply governance and investment arrangements that fulfil the needs of the policy cycle.

## Evidence and Scenarios

**Energy and emissions modelling of transport in Ireland is predominantly focused on compliance with greenhouse gas and air pollution targets, in the medium term, up to 2030 and 2040.**

A framework for ‘sustainable mobility transformation’ has key requirements that have been fleshed out in detail internationally, including in the IPCC assessment reports. A core approach is to support decision-makers with appropriate evidence that allows the different potential long-term pathways, and their implications, to be more clearly understood. Energy and emissions modelling of transport in Ireland is predominantly focused on compliance with greenhouse gas and air pollution targets, in the medium term up to 2030, and recently to 2040. The cost effectiveness analysis and marginal abatement cost curves that are used to inform mitigation policy choice are limited to ‘improve’ measures for energy and carbon efficiency. This leaves key gaps in exploring the priority measures of ‘avoid’ and ‘shift’. In addition, these models focus on the cost per tonne of emissions mitigated, and, while this is one of the relevant considerations, it could also act as a barrier to change. This is particularly the case where capital costs are higher, and where the full benefits of new measures to society cannot be fully captured, which are common characteristics of public transport projects.

Future visions and scenarios, including modelled pathways, are important contributors to policymaking. This evidence allows policymakers to consider the outcomes and implications of different paths. Existing modelling of emissions mitigation, by improvements in efficiency, needs augmentation with scenarios that allow consideration of the implications of major long-term changes in spatial and demand patterns, and in the potential for a considerable shift in modes to active and public transport. Scenario methods allow for wide variety in the complexity and approach to visions and analyses of potential future change. These range from summary assessments that draw on existing worldwide evidence, through narrative visions built with and by policymakers, using structured and facilitated strategic techniques, to modelled pathways that seek to quantify the impact of measures.

Some advantages of modelled pathways are the indication of potential quantified emissions reductions they can provide, and also the comparability of measures. For example, in terms of ‘avoid’ measures, modelling could help to identify the higher emissions implications of further low-density spatial planning, and also the effectiveness of deeper measures for shifting to active and public transport modes. Modelling pathways that consider ASI measures, in the form of reduced demand and mode shift, would require further model development in Ireland. It would be useful to consider the relationship between enhancing modelling capabilities and the existing analytical contributions of the Department of Transport, Tourism and Sports, in its National Investment Framework for Transport in Ireland, and the demand forecasts in the Strategic Investment Framework for Land Transport.

As modelling and scenario studies are key tools used in support of policymaking, the enhancement of the capacity to model or quantify the spatial planning ‘avoid’ measures and transport planning ‘shift’ measures could assist in enabling further policy development in these areas. Sims *et al.* (2014) provide a comprehensive review of the sectoral transport-specific models that are designed specifically to consider compact spatial planning and mode shift measures.<sup>10</sup>

As detailed by the IPCC, supporting a sustainable mobility transformation requires the use of long-term horizons in scenario studies, to 2050 and beyond (Sims *et al.*, 2014). The panel highlights that the lifetimes of transport infrastructure range from 50 to more than 100 years, a key factor in lock-in. The application of long time horizons is therefore one of the critical conditions of sustainable mobility and is mirrored in the need for long-term visions and planning.

Sustainable urban mobility planning (SUMP) is now the default transport-planning concept in the EU, arising from the Urban Mobility Package (COM(2013) 91), with guidelines issued by the European Commission (Rupprecht Consult, 2019). Long-term scenario and vision building are central to this process, with good practice examples as diverse as the central region of Macedonia and cities such as Lisbon, Manchester and Prague (Directorate-General for Mobility and Transport, 2019b). SUMP requires the integration of key functions of spatial and mobility planning, and in Edinburgh, SUMP was led by the council’s spatial policy team (Rupprecht Consult, 2019). The Greater Manchester SUMP integrated spatial and mobility planning after recognising the growing pressure of population growth in the region (Directorate-General for Mobility and Transport, 2019b), an appropriate comparison for Ireland. Integration of policy actors and related themes are important considerations, often including multi-level

<sup>10</sup> These include land use planning that favours high-density or polycentric urban forms; public transport-oriented developments with mixed uses; and high-quality city environments (Sims *et al.*, 2014, p. 637).



institutional participation of relevant local authorities with national Departments and agencies, and even harmonising climate-neutral policymaking with spatial and transport planning. National integration with emissions policy and modelling is exemplified by the German federal greenhouse gas-neutral plan to reduce transport emissions by 100 per cent by 2050, with 50 per cent based on avoid and shift (German Environment Agency, 2014).

Long-term analysis is an enabler of long-term spatial and transport planning. Timescales of 30 years plus, to 2050 and beyond, allow the analysis, and ultimately policy planning, to envision the major system shifts that can overcome carbon lock-in. The current medium-term focus in mitigation, predominantly to 2030, also prevents full consideration of the key priority avoid and shift measures, some of which emerge more significantly from longer time horizons.

A transformation focus includes avoid and shift measures, and can integrate the variety of policy objectives that are relevant to transport. By definition, this requires long-term scenarios that also analyse significant structural and systems change. In the political process that follows, by understanding these alternative pathways, and their environmental, social and economic implications, policymakers can then consider which path delivers the best outcomes, across all policy objectives.

### Topic Box 11.3 EPA Research Programme 2014-2020

#### Environment and Transport

Since 2016, the EPA has funded up to 20 new research projects relevant to the Environment and Transport area, representing a commitment of €3.1 million. These projects were funded mostly under the Climate and Sustainability Pillars of the EPA Research Programme 2014-2020.

#### Examples of EPA-funded research projects include research on

- production of advanced gaseous biomethane transport fuel in an integrated circular bioenergy system
- metrics of climate neutrality in the context of deep decarbonisation in Ireland by 2050
- critical infrastructure vulnerability to climate change
- eco-driving: trends and potential impacts for Irish heavy-duty vehicles
- emissions from and fuel consumption associated with off-road vehicles and other machinery
- behavioural response to sustainable travel policy incentives.

More information is available from <http://www.epa.ie/researchandeducation/research/>

## Policies and Measures

**A reliance on measures for improving the energy and carbon efficiency of vehicles is evident in Irish policy. We also need to consider avoiding journeys where possible, through innovative spatial and transport planning for compact development, and for shifting to low-carbon transport systems of walking, cycling and public transport.**

While improving energy and carbon efficiency by technical means is a necessary approach, it is unlikely to deliver sustainable mobility or climate neutrality on its own. It is known that improving vehicle decarbonisation is required, including alternative powertrains and biofuels, yet it is also known that relying on these measures is not optimal, and may not even be feasible (Rogelj *et al.*, 2018; EEA, 2019a; McKinnon, 2019; Windisch, 2019). Relying on decarbonisation continues the path already seen in Ireland in recent decades. With insufficient action on avoid and shift, this could lead to an increase in the number of journeys by private car, truck and other road vehicles. This path would drive a range of negative side effects, directly linked to use of road vehicles, including air pollution,<sup>11</sup> noise, congestion and road traffic accidents, and impose unnecessary costs on human wellbeing, the economy and the environment. However, a comprehensive package of measures that could deliver an avoid and shift transformation, instead of marginal and efficiency change, has yet to be articulated for Ireland. The comprehensive approach in Germany, previously alluded to, is a useful example. The IPCC also provides a vital summary table of the ASI measures, assessing both short- and long-term possibilities for reducing greenhouse gas emissions, with their barriers and opportunities (Sims *et al.*, 2014, pp. 634-636).

Considering that ASI exists as a hierarchy (see Figure 11.4), policy first needs to consider changes to spatial planning and demand management. This will require increased density for new development, and plans to deal with the legacy of lock-in from past urban sprawl and road-dominated infrastructure planning. The NPF envisages a shift away from a low-density business-as-usual development model, setting Ireland's first brownfield development target, and at the same time may also enable a large degree of greenfield development, and more extensive housing provision in rural areas. The legislation underpinning the NPF commits the government to regular reviews of the NPF, offering further opportunities to enhance the level of ambition in relation to urban consolidation and avoidance of urban sprawl, as the

<sup>11</sup> All roads vehicles produce particulates from tyre and brake wear. Although electric vehicles prevent particulates from engine fuel burning, they cannot prevent those other forms of air pollution. Electric vehicles also contribute to increased greenhouse gases in the countries in which they are produced.



government comes to understand the mechanics of implementing its starting brownfield development targets. A number of relevant policy processes are noted in the following section.

Enhanced short-term actions to prevent further sprawl and the development of emissions-intensive infrastructure, and to overcome barriers to active and public transport options, may also be required (Sims *et al.*, 2014). Avoiding sprawl means redoubling efforts to promote the alternative of well-located, good-quality, affordable, and active and public transport-centred communities – otherwise known as compact development in the NPF.

Topic Box 11.4 details what, in a major report, the European Environment Agency and the Swiss Federal Office of the Environment described as essential guidelines to prevent sprawl (EEA and FOEN, 2016).

#### Topic Box 11.4 Five Essential Guidelines to Prevent Urban Sprawl from the European Environment Agency (Source: EEA)

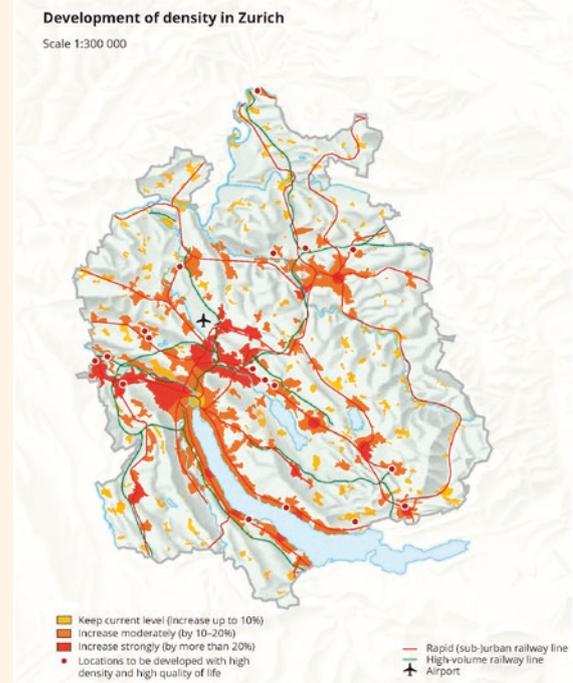
Five essential guidelines to support efforts to control urban sprawl:

- a clear separation of building zones and non-building zones, and long-term settlement restriction
- building in only designated building zones
- preventing the dispersed expansion of built-up areas
- the densification of existing built-up areas and minimum densities of new built-up areas
- the integrated planning of transport and settlement development.

Urban sprawl is essentially a permanent spatial pattern, and sustainability becomes more and more difficult to achieve as sprawl advances. Addressing sprawl, while accommodating population growth and urbanisation, requires increased density of development and integrated planning of sustainable transport. This requires redevelopment of low-density land in key locations, for compact development and a variety of uses. Dense village-centre type development, and block and city zone development, can be combined with mixed use to accommodate employment. Involving both national and local planning functions, developments would need the provision of high-quality public amenities and services, to promote attractiveness. Plans to avoid urban sprawl while accommodating population growth in the Swiss Canton of Zurich are discussed in Topic Box 11.5.

#### Topic Box 11.5 Avoiding Urban Sprawl in Zurich

**Map 11.1** An example of densification from the Canton of Zurich, Switzerland (Source: Regierungsrat Kanton Zürich, 2014)



The EEA discusses the case of the Canton of Zurich, where planning will densify existing built-up areas by approximately 20 per cent by 2040, effectively eliminating urban sprawl (EEA, 2016). Research in the Swiss national research programme on new urban quality concluded that the urbanisation of suburban areas is one of the main tasks for society in the 21st century, to accommodate a 20 per cent growth in population.

Almost no further expansion of built-up areas is now allowed in the Canton of Zurich. Therefore, any increases in population have to be accommodated mostly in the existing built-up areas. The necessary densifications are relatively modest: on average, less than 20 per cent of the existing density as shown in Map 11.1. The densification takes the existing settlement types into account. Rural areas keep their rural character with densification of less than 10 per cent. The highest levels of densification (> 20%) occurs in the suburban areas shown in red.



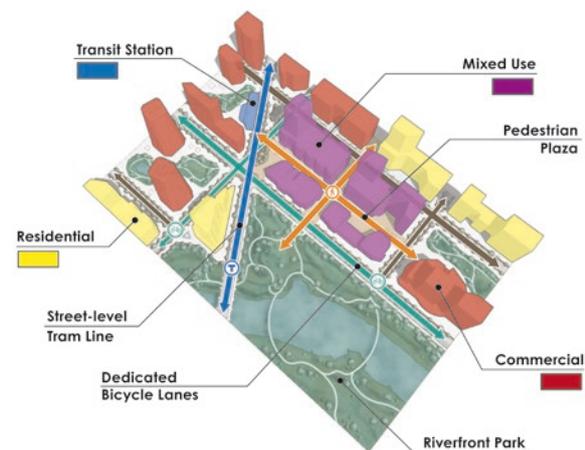
Spatial and development planning needs to be deeply integrated with long-term sustainable transport planning, for active and public modes, to 2050 and beyond. This is a careful synchronisation and coordination, working in tandem with and reinforcing each other. Transit-oriented development allows the integration of planning for settlement with strategic policy for active and public transport infrastructure (Seto *et al.*, 2014). Since the middle of the 20th century, transit-oriented development has been applied successfully in many cities, from Amsterdam, Stockholm and Vienna to Hong Kong, Melbourne and Vancouver, to promote dense and compact urban forms within walking and cycling distance of public transport. This has the impact of both avoiding journeys and cutting their distances, and making sustainable transport modes convenient and desirable, by concentrating urban development around public transport hubs. Applied to freight, it involves planning for economic activity that leads to concentrating the highest density of goods movement near rail. The feasibility of long-term expansion of Irish rail freight needs to be considered, in line with linkages between rail, road and shipping networks, the logistics of goods movement and advanced communication technologies.

The IPCC notes that urban redevelopment and investments in new infrastructure, linked with integrated urban planning, transit-oriented development and more compact urban forms that support cycling and walking, can all lead to modal shifts. Such mitigation measures could evolve to possibly reduce greenhouse gas intensity by 20-50 per cent below the 2010 baseline by 2050 (Sims *et al.*, 2014), depending on policy and country. Applying the integrated approach involves a sustainability hierarchy, from avoid and reduce, to shifting to active modes and public transport. It requires giving priority to expanding walking and cycling, followed by rail and then bus. The EEA highlights the importance of the change between modes as first-/last-/only-mile options (EEA, 2020b), acknowledging that public transport hubs are not destinations. Effective planning of modal shift requires systemic provision for active and public transport modes, at journey beginning and end. It facilitates the use of the public transport system as the backbone of mobility, without the private car. Mobility sharing and information technology also offer approaches to assist mode shift and reductions in demand.

The measures included in the National Development Plan and NPF are a useful addition. It is now necessary to advance the discussion by considering the potential of deepening avoid and shift measures in the long term, to 2050 and beyond. Discussions that consider enabling a deepening of avoid and shift have begun to emerge in Ireland (CCAC, 2019b), including transit-oriented development (NTA, 2013; NESAC, 2019); the hierarchy of active and public modes (JCCA, 2019); shifting to walking and cycling (DTTAS, 2019b); rail expansion (CCAC, 2019a; DTTAS, 2019c); and high-speed rail (An Taoiseach, 2019).

The dublinbikes scheme is an example of an effective measure to shift journeys to active modes in Ireland. Widely regarded as one of the most successful shared bike schemes in Europe, dublinbikes was established as a partnership between Dublin City Council and JC Decaux in 2009, and has been expanded since then. This public bicycle rental scheme is free for the first half hour. It now has more than 100 stations across the city, generating over 30 million bicycle journeys since opening, 96 per cent of which have been for free (dublinbikes, 2020). Other cities have been successful in establishing successful cycling cultures. Beside the recognised cities of Amsterdam and Copenhagen, there are solutions around cycling being rolled out in cities such as Seville. Here 80 km of segregated cycling lanes was constructed in one go. In Seville, the 'build it and they will come' approach increased cycling from an average of 6000 to 67,000 bicycle trips daily. The network has now grown to 180 km, and the aim is to increase the current 9 per cent of trips a day to 15 per cent.

To illustrate a further success story of modal shift internationally, Topic Box 11.6 discusses a shift to public transport in Vienna.



Urban design of transit-oriented development (Source: Rotbert, J.)



### Topic Box 11.6 Shifting to Public Transport in Vienna



Vienna is a city celebrated for its high quality of life, and also its approach to modal shift to public transport. The ‘Vienna model’ featured at the EPA’s National Climate Conference in 2019. The city introduced an unlimited public transport ticket for a flat fee of €365 a year in 2012, far cheaper than the European average. The city has benefited from policy that has consistently prioritised the development and expansion of its train, metro, tram and bus lines. The new €1 a day ticket is aimed at encouraging a switch from the private car, by increasing use of the available public transport. Additional costs, on top of the annual public subsidy of €700 million, are met by a major increase in the sale of annual tickets and additional measures.

The Vienna model has been successful in supporting modal shift, with public transport journeys growing to 950 million in 2017, almost 20 per cent higher than 2007. Public transport now supplies 38 per cent of journeys, with just 29 per cent by private car according to the city transport company, Wiener Linien. They estimate that every person who switches to public transport saves up to 1.5 tonnes of carbon dioxide per year, with reductions in air pollution in parallel (Wiener Linien, 2019). Vienna aims for a vision of desirable and affordable places to live, delivering both numbers of housing and quality of life. To achieve this, the mobility element of this vision integrates spatial and transport planning, and also prioritises the active modes of walking and cycling, along with public transport.

The final step in the hierarchy is to consider the ‘improve’ approach to remove carbon emissions from vehicles. This is achieved through electric and other zero carbon technology, across passenger and freight activity, both public and private. Decarbonisation involves maximising alternative powertrains, including electric and hydrogen fuel cells, and also biofuels. The decarbonisation of public transport also facilitates the win-win of improving air quality, particularly in challenging urban locations. Public sector leadership has an important role to play in catalysing the move to low-carbon vehicles, in the fleet procurement of local authorities, state agencies and public institutions.

## Governance and Investment

The long-term transformation required is a complex task, involving trade-offs between the interests of different stakeholders, operating at different scales.

The choice of a sustainable pathway can be enabled by providing appropriate governance and institutional structures for implementation and review, underpinned by evidence and knowledge capacity, and, critically, supported by political will and targeted investment.

The transformation required is a complex task, involving trade-offs between the interests of different stakeholders, operating at different scales (Devaney and Torney, 2019). Governance involves consideration of the interests of institutional, society and market actors together, to understand what shared visions can achieve, and what tensions must be resolved. This requires public participation and dialogue, and the centrality of just transition. The recent additions to Irish climate policy implementation and monitoring frameworks, under the Climate Action Plan, are an example of the institutional and policy structures that can be harnessed to enhance coordinated and integrated governance for sustainable mobility.

A key finding from the IPCC, through policy experience globally, is the need for long-term national strategies and visions, supported by short-term regional and local implementation plans (Sims *et al.*, 2014). In Ireland, this requires giving priority to enhanced evidence-based integration of spatial and transport planning, with investment targeting substantial change in current patterns and outcomes.

Institutional arrangements for long-term spatial and transport planning in Ireland are improving to the point where policymakers can begin to consider how we can avoid journeys in the first place, through better spatial planning and demand management, working in concert with the mobility planning and investment necessary to bring about a major shift from the private car to the sustainable modes of walking, cycling and public transport. Further capacity building, across the relevant institutions, can support the practice of long-term integrated spatial and transport planning.

A prerequisite for the more joined-up approach to sustainable and climate action-centred spatial and transport planning is policymaking structures at the appropriate geographical level. Those making the decisions – in Ireland the elected members of the local government system – must be equipped with the relevant information to make decisions in line with sustainable outcomes. The issue of the appropriate geographical level is critical because strategic action on climate-centred spatial and transport planning requires the consideration of issues that must take account of, but go beyond, the level of individual local authorities, of which there are 31 in Ireland.



In addition to the NPF, the regional assemblies have recently adopted regional spatial and economic strategies, which have included the first metropolitan area strategic plans for the major cities. The National Transport Authority has also begun the process of preparing metropolitan area transport strategies, in conjunction with the local authorities. Furthermore, under Action 65 of the Climate Action Plan, the Department of Housing, Local Government and Heritage will prepare a climate action toolkit and audit framework, for local authority development planning. Local authority spatial plans must be reviewed to take on board the new national and regional policies, and will be subject to oversight by the Office of the Planning Regulator. Taking account of these advances, substantial institutional change has taken place, which is highly relevant to enhancing the scope for a strategic approach to integrated spatial and transport planning for sustainable mobility.

In parallel, the crucial top-down role of investment in driving change is widely recognised. Modifications to planning density can come at little or no capital cost, requiring local development plans to come into alignment. However, in some cases they may entail capital costs of redevelopment of existing settlement in strategic locations – effectively a housing cost. Infrastructure for modal shift entails capital costs that must be considered. This requires the identification of funding streams to support new infrastructure development and deliver the many synergies and benefits it offers. Opportunities to provide funding have been considered by the National Economic and Social Council (NESC, 2019).

## 5. Conclusions

### Environmental Pressures and Transport

Transport is a leading source of environmental pressures in Ireland, including greenhouse gas emissions, air pollution and noise emissions. While some air pollutants can be effectively reduced by technological means, international evidence has clearly shown that greenhouse gas emissions are a growing problem. The analysis of historic driving forces suggests that the push of increased economic activity and population growth has coincided with public policy and private market factors that have often favoured more dispersed settlement patterns, road development and the private car. Transport greenhouse gas emissions in Ireland need to be eliminated by 2050, and yet the trends are not responding in the right direction. On its current pathway, the transport sector will not deliver these reductions. Changing to a pathway to address these challenges will require fundamental transition and significant policy change (CCAC, 2019a).

### Sustainable Mobility Transformation

To make Ireland 'a leader in responding to climate disruption', as per the Climate Action Plan (Government of Ireland, 2019, p. 37), a fundamental change in Irish transport policy is required. This needs to be aimed at delivering long-term avoid and shift, followed by improve. Measures that reduce greenhouse gases can also deliver co-benefits of reduced air pollution and noise emissions and improve wellbeing and the economy by tackling growing traffic congestion. Addressing the challenge with the urgency implied by 'early action' will offer the ability not just to reduce environmental pressures, but to improve health outcomes and to counter the higher economic costs of locked-in pathways. A sustainable mobility transformation offers numerous benefits for wellbeing, for society and for the economy.



### Avoid-Shift-Improve

A standard policy approach for changing transport systems has emerged internationally, as a hierarchy of avoid-shift-improve, which is about using a holistic and integrated systems perspective. Avoid is achieved through spatial planning and demand management; shift through moving to active modes of walking and cycling, followed by rail and bus; and, finally, improve through the energy and carbon efficiency of vehicles. The change in framing and thinking recognises that improvements in energy and carbon efficiency are necessary but not sufficient. Reaching a sustainable transformation of mobility requires an acceleration of all measures, including avoid and shift (Rogelj *et al.*, 2018). This approach offers a plethora of benefits, but also has key requirements. The process begins by taking long-term spatial and transport planning together, followed by the last step, switching to carbon-free vehicles and fuels.

Current greenhouse gas mitigation policy mainly focuses on improving carbon efficiency, through increasing electric vehicle numbers by 2030. Energy and carbon efficiency improvement is important, and the public sector can play a leadership role in enabling it. The decarbonisation of public transport will also further improve air quality. However, as efficiency is an 'end of pipe' measure, when pursued on its own it is not optimal and may not be feasible. Continuing the current path will deepen lock-in to a 'greener congestion' that is difficult to escape. Comparison with international evidence suggests that the avoid and shift measures in Ireland could benefit from enhancement. To effectively implement the framing and thinking of ASI, Ireland needs action in three key areas, described earlier in this chapter: (i) evidence and scenarios, (ii) policies and measures and (iii) governance and investment.



### Long Term Systemic Approach

Firstly, developing evidence and scenarios involves implementing analytical, scenario and visioning techniques that integrate to include all avoid-shift-improve approaches. Specifically, they must also include demand reduction and mode shift measures, augmenting the current modelled pathways that address energy and carbon efficiency. Secondly, a well-designed transport system is a project of transformation towards sustainability, and must be supported by appropriate policies and measures. A long-term systemic approach is crucial to this objective. It requires deep integration of spatial, transport and transition planning, at all levels, to implement measures that deliver compact development, and expand active and public transport infrastructure for modal shift, to overcome the dominance of the private car.

Finally, in practical terms, this requires backing by appropriate governance and investment to complete the policy cycle. This involves a long-term strategic approach to integrate policy, facilitate participation and just transition, manage trade-offs and achieve win-wins. It requires institutional structures that support implementation of sustainable mobility transformation, from national to local level, and policy development and review arrangements that can effectively deliver. While this approach offers the potential to avoid the significant economic costs associated with environmental impacts, urban sprawl and traffic congestion, it also requires consideration of targeted investment, particularly for enhanced active and public transport infrastructure.

### Moving Forward with the Ambition of Climate Neutrality

Recent policy and institutional reforms, to enhance the strategic capability of Ireland's spatial and transport-planning processes, are a positive start. But this process needs follow-through, and ongoing enhancement of the ambition for transformational change, if we are to realise the promise of the ASI approach. Metropolitan planning and transport policies are being developed, and an independent body has been put in place to oversee the spatial plan-making process at regional and local levels, which has climate action as a key part of its assessment criteria. The scene is now set for the honing of strategic and analytical capabilities, in relation to the sustainability requirements of our evolving and future planning and transport policies.



## Chapter Highlights for Environment and Transport



The transport sector has a significant impact on the environment, including being responsible for 20 per cent of Ireland's greenhouse gas emissions. A sustainable mobility transformation is required, with the next decade crucial, whereby necessary journeys are made by sustainable modes such as walking, cycling and public transport, followed by using electric vehicles where unavoidable. For this transformation to happen we need to start fast-tracking the measures in the Climate Action Plan and other necessary measures.



Long-term, integrated spatial and transport planning can achieve compact development and move trips to rail, bus, cycling and walking. Shifting to these modes is an essential part of a sustainable and climate-neutral transition for the transport sector.



While challenging, the long-term changes required in transport can deliver multiple benefits in reducing greenhouse gases, tackling growing traffic congestion, reducing air pollution and noise emissions, and enhancing our wellbeing and the economy.



## References

- Ahrens, A. and Lyons, S., 2019. Changes in land cover and urban sprawl in Ireland from a comparative perspective over 1990-2012. *Land* 8: 1-14.
- An Taoiseach, 2019. Varadkar: bridge between North and Scotland 'worth examining' but UK must pay. Available online: <https://www.irishtimes.com/news/politics/varadkar-bridge-between-north-and-scotland-worth-examining-but-uk-must-pay-1.4124732> (accessed 21 January 2020).
- Braithwaite, I., Zhang, S., Kirkbride, J., Osborn, D. and Hayes, J., 2019. Air pollution (particulate matter) exposure and associations with depression, anxiety, bipolar, psychosis and suicide risk: a systematic review and meta-analysis. *Environmental Health Perspectives* 127(12): 126002.
- Carthy, P., Ó Domhnaill, A., O'Mahony, M., Nolan, A., Moriarty, F., Broderick, B., Hennessy, M., Donnelly, A., Naughton, O. and Lyons, S., 2020. Local NO<sub>2</sub> concentrations and asthma among over-50s in Ireland: a microdata analysis. *International Journal of Epidemiology*, in press. <https://doi.org/10.1093/ije/dyaa074>
- CCAC (Climate Change Advisory Council), 2019a. *Annual Review 2019*. Climate Change Advisory Council. Available online: <http://www.climatecouncil.ie/media/Climate%20Change%20Advisory%20Council%20Annual%20Review%202019.pdf> (accessed 4 January 2019).
- CCAC (Climate Change Advisory Council), 2019b. Secretariat paper: 'setting the scene'. Paper presented to Climate Change Advisory Council workshop on 'Transition of Irish Transport: Issues, Approaches and Options'. Available online: <http://www.climatecouncil.ie/media/Transpor%20Transition%20Paper%201%20Setting%20the%20scene.pdf> (accessed 21 January 2020).
- Crippa, M., Oreggioni, G., Guizzardi, D., Muntean, M., Schaaf, E., Lo Vullo, E., Solazzo, E., Monforti-Ferrario, F., Olivier, J.G.J. and Vignati, E., 2019. *Fossil CO<sub>2</sub> and GHG Emissions of All World Countries – 2019 Report*. EUR 29849 EN. Publications Office of the European Union, Luxembourg.
- CSO (Central Statistics Office), 2017. National Travel Survey: key findings. Available online: <https://www.cso.ie/en/releasesandpublications/ep/p-nts/nts2016/keyf/> (accessed 11 June 2018).
- CSO (Central Statistics Office), 2019a. National income and expenditure 2018, gross national income at constant market prices. Available online: <https://www.cso.ie/en/statistics/nationalaccounts/nationalincomeandexpenditureannualresults/> (accessed 2 January 2020).
- CSO (Central Statistics Office), 2019b. Environmental indicators Ireland 2019. Available online: <https://www.cso.ie/en/releasesandpublications/ep/p-eii/eii19/transport/> (accessed 3 January 2020).
- CSO (Central Statistics Office), 2020a. National Travel Survey 2019: how we travelled. Available online: <https://www.cso.ie/en/releasesandpublications/ep/p-nts/nationaltravelsurvey2019/howwetravelled/> (accessed 30 July 2020).
- CSO (Central Statistics Office), 2020b. Statistical product – vehicle licensing statistics annual series. Available online: [https://statbank.cso.ie/px/pxeirestat/Database/eirestat/Vehicle%20Licensing%20Statistics%20Annual%20Series/Vehicle%20Licensing%20Statistics%20Annual%20Series\\_statbank.asp?sp=Vehicle%20Licensing%20Statistics%20Annual%20Series&Planguage=0&ProductID=DB\\_TE](https://statbank.cso.ie/px/pxeirestat/Database/eirestat/Vehicle%20Licensing%20Statistics%20Annual%20Series/Vehicle%20Licensing%20Statistics%20Annual%20Series_statbank.asp?sp=Vehicle%20Licensing%20Statistics%20Annual%20Series&Planguage=0&ProductID=DB_TE) (accessed 25 February 2020).
- CSO (Central Statistics Office), 2020c. FPM01: fuel excise clearance by fuel type and month. Available online: [https://statbank.cso.ie/px/pxeirestat/Database/eirestat/Fuel%20Excise%20Clearances/Fuel%20Excise%20Clearances\\_statbank.asp?SP=Fuel%20Excise%20Clearances&Planguage=0](https://statbank.cso.ie/px/pxeirestat/Database/eirestat/Fuel%20Excise%20Clearances/Fuel%20Excise%20Clearances_statbank.asp?SP=Fuel%20Excise%20Clearances&Planguage=0) (accessed 4 August 2020).
- Cummins, D., 2009. Rail freight in Ireland. Booz & Company, lecture to Engineers Ireland, 16th September, 2009.
- Devaney, L. and Torney, D., 2019. *Advancing the Low-Carbon Transition in Irish Transport*. Research Series Paper No. 13, May. National Economic and Social Council, Dublin.
- Directorate-General for Mobility and Transport, 2019a. *Handbook on the External Costs of Transport*. Available online: <https://op.europa.eu/en/publication-detail/-/publication/e021854b-a451-11e9-9d01-01aa75ed71a1/language-en/format-PDF> (accessed 24 February 2020).



Directorate-General for Mobility and Transport, 2019b. *Sustainable Urban Mobility Planning and Governance Models in EU Metropolitan Regions*. Available online: [https://www.eltis.org/sites/default/files/annex\\_good\\_practices\\_collection.pdf](https://www.eltis.org/sites/default/files/annex_good_practices_collection.pdf) (accessed 24 February 2020).

DTTAS (Department of Transport, Tourism and Sport), 2019a. Oireachtas Joint Committee on Climate Action, Wednesday 27 November 2019: Statement by the Department of Transport, Tourism and Sport. Available online: [https://data.oireachtas.ie/ie/oireachtas/committee/dail/32/joint\\_committee\\_on\\_climate\\_action/submissions/2019/2019-11-28\\_opening\\_statement-deirdre-hanlon-assistant-secretary-public-transport-sustainability-and-climate-change-department-of-transport-tourism-and-sport\\_en.pdf](https://data.oireachtas.ie/ie/oireachtas/committee/dail/32/joint_committee_on_climate_action/submissions/2019/2019-11-28_opening_statement-deirdre-hanlon-assistant-secretary-public-transport-sustainability-and-climate-change-department-of-transport-tourism-and-sport_en.pdf) (accessed 7 January 2020).

DTTAS (Department of Transport, Tourism and Sport), 2019b. *Sustainable Mobility Policy Review, Background Paper 2: Active Travel*. Department of Transport, Tourism and Sport, Dublin.

DTTAS (Department of Transport, Tourism and Sport), 2019c. *Sustainable Mobility Policy Review Background Paper 5: Greener Buses – Alternative Fuel Options for the Urban Bus Fleet*. Department of Transport, Tourism and Sport, Dublin.

dublinbikes, 2020. Just Eat dublinbikes – latest figures 29th February 2020. Available online: <http://www.dublinbikes.ie/Magazine/Reports/Just-Eat-dublinbikes-latest-figures> (accessed 24 April 2020).

EEA (European Environment Agency), 2016. *Transitions towards a More Sustainable Mobility System – TERM 2016: Transport Indicators Tracking Progress towards Environmental Targets in Europe*. EEA Report No. 34/2016. EEA, Copenhagen. Available online: <https://www.eea.europa.eu/publications/term-report-2016> (accessed 30 October 2020).

EEA (European Environment Agency), 2019a. *The European Environment – State and Outlook 2020: Knowledge for Transition to a Sustainable Europe*. EEA, Copenhagen. Available online: <https://www.eea.europa.eu/publications/soer-2020> (accessed 21 January 2020).

EEA (European Environment Agency), 2019b. *Air Quality in Europe – 2019 Report*. EEA, Copenhagen. Available online: <https://www.eea.europa.eu/publications/air-quality-in-europe-2019>.

EEA (European Environment Agency), 2020a. Data viewer on greenhouse gas emissions and removals – EU Member States – emission source IPCC sector 1.D.1.a (International Aviation Memo item). Available online: <https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer> (accessed 25 February 2020).

EEA (European Environment Agency), 2020b. *The First and Last Mile – the Key to Sustainable Urban Transport: Transport and Environment Report 2019*. European Environment Agency. Available online: <https://www.eea.europa.eu/publications/the-first-and-last-mile/> (accessed 24 February 2020).

EEA (European Environment Agency) and FOEN (Federal Office of the Environment), 2016. *Urban Sprawl in Europe: Joint EEA-FOEN Report*. Available online: <https://www.eea.europa.eu/publications/urban-sprawl-in-europe> (accessed 4 January 2020).

EPA (Environmental Protection Agency), 2019. *Air Quality in Ireland 2018*. EPA, Wexford, Ireland.

EPA (Environmental Protection Agency), 2020a. *Ireland's National Inventory Report 2020 Greenhouse Gas Emissions 1990-2018*. Environmental Protection Agency, Wexford, Ireland.

EPA (Environmental Protection Agency), 2020b. *Informative Inventory Report 2020 Air Pollutant Emissions in Ireland 1990-2018*. Available online: <https://www.epa.ie/pubs/reports/air/airemissions/airpollutantemissions/iir2020/> (accessed 4 August 2020).

EPA (Environmental Protection Agency), 2020c. *Ireland's Greenhouse Gas Emissions Projections 2019-2040*. Available online: <http://www.epa.ie/pubs/reports/air/airemissions/ghgprojections2019-2040/> (accessed 4 August 2020).

EPA (Environmental Protection Agency), 2020d. Recent trends in nitrogen dioxide (NO<sub>2</sub>) levels in air (Ireland). Available online: <https://www.epa.ie/newsandevents/news/pressreleases2020/name,69166,en.html> (accessed 4 August 2020).

EPA (Environmental Protection Agency), 2020e. *Air Quality in Ireland 2019*. EPA, Wexford, Ireland.



EPA (Environmental Protection Agency), 2020f. *Ireland's Provisional Greenhouse Gas Emissions, 1990-2019*. Available online: <http://www.epa.ie/ghg/documents/> (accessed 20 November 2020). Additional data received from Damien Fahey, personal communication.

Eurostat, 2020. Population on 1 January. Available online: <https://ec.europa.eu/eurostat/databrowser/view/tps00001/default/table?lang=en> (accessed 24 April 2020).

German Environment Agency, 2014. *Germany in 2050 – A Greenhouse Gas-Neutral Country*. Umweltbundesamt. Available online: [https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/07\\_2014\\_climate\\_change\\_en.pdf](https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/07_2014_climate_change_en.pdf) (accessed 22 February 2020).

Government of Ireland, 2018. *Project Ireland 2040 – National Planning Framework*. Available online: <http://nfp.ie/wp-content/uploads/Project-Ireland-2040-NPF.pdf> (accessed 4 January 2019).

Government of Ireland, 2019. *Climate Action Plan 2019 – To Tackle Climate Breakdown*. Department of Communications, Climate Action and Environment. Available online: <https://www.gov.ie/en/publication/ccb2e0-the-climate-action-plan-2019/> (accessed 19 November 2020).

INRIX, 2018. INRIX 2019 Global Traffic Scorecard. Available online: <https://inrix.com/scorecard/> (accessed 31 July 2020).

JCCA (Joint Committee on Climate Action), 2019. *Climate Change: A Cross-Party Consensus for Action*. Report of the Joint Committee on Climate Action. Available online: [https://data.oireachtas.ie/ie/oireachtas/committee/dail/32/joint\\_committee\\_on\\_climate\\_action/reports/2019/2019-03-28\\_report-climate-change-a-cross-party-consensus-for-action\\_en.pdf](https://data.oireachtas.ie/ie/oireachtas/committee/dail/32/joint_committee_on_climate_action/reports/2019/2019-03-28_report-climate-change-a-cross-party-consensus-for-action_en.pdf) (accessed 21 January 2020).

McKinnon, A.C., 2018. *Decarbonising Logistics: Distributing Goods in a Low Carbon World*. Kogan Page, London.

McKinnon, A.C., 2019. Decarbonizing freight transport: review of opportunities and challenges. Available online: <http://www.climatecouncil.ie/media/Dr%20Alan%20McKinnon%20-%20Decarbonising%20Freight%20Transport%20-%20Review%20of%20Opportunities%20and%20Challenges.pdf> (accessed 3 January 2020).

Mulholland, E., Rogan, F., Mac Uidhir, T. and Ó Gallachóir, B., 2020. *Opportunities to Decarbonise the Irish Transport Sector*. Available online: <http://www.epa.ie/researchandeducation/research/researchpublications/researchreports/research321.html> (accessed 4 August 2020).

NESC (National Economic and Social Council), 2019. *Transport-orientated Development: Assessing the Opportunity for Ireland*. NESC. Available online: [http://files.nesc.ie/nesc\\_reports/en/148\\_TOD.pdf](http://files.nesc.ie/nesc_reports/en/148_TOD.pdf) (accessed 21 January 2020).

NTA (National Transport Authority), 2013. *Planning and Development of Large-Scale, Rail Focussed Residential Areas in Dublin*. NTA, Dublin.

OECD (Organisation for Economic Co-operation and Development), 2018. *Rethinking Urban Sprawl: Moving towards Sustainable Cities*. OECD Publishing, Paris. Available online: [https://www.oecd-ilibrary.org/environment/rethinking-urban-sprawl\\_9789264189881-en](https://www.oecd-ilibrary.org/environment/rethinking-urban-sprawl_9789264189881-en) (accessed 19 August 2020).

O'Mahony, T., Zhou, P. and Sweeney, J., 2012. The driving forces of change in energy-related CO<sub>2</sub> emissions in Ireland: a multi-sectoral decomposition from 1990 to 2007. *Energy Policy* 44: 256-267.

Quintyne, K.I., Sheridan, A., Kenny, P. and O'Dwyer, M., 2020. Air quality and its association with cardiovascular and respiratory hospital admissions in Ireland. *Irish Medical Journal* (6): P92

Regierungsrat Kanton Zürich, 2014. *Langfristige Raumentwicklungsstrategie Kanton Zürich*. Kanton, Zürich.



Rogelj, J., Shindell, D., Jiang, K., Fifita, S., Forster, P., Ginzburg, V., Handa, C., Kheshgi, H., Kobayashi, S., Kriegler, E., Mundaca, L., Séférian, R. and Vilarinho, M.V., 2018. Mitigation pathways compatible with 1.5°C in the context of sustainable development. In Masson-Delmotte, V., Zhai, P., Pörtner, H.-O., Roberts, D., Skea, J., Shukla, P.R., Pirani, A., Moufouma-Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M. and Waterfield, T. (eds), *Global Warming of 1.5°C: An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*. pp. 93-174.

Rupprecht Consult, 2019. *Guidelines for Developing and Implementing a Sustainable Urban Mobility Plan*, 2nd edition. Available online: [https://www.eltis.org/sites/default/files/sump-guidelines-2019\\_mediumres.pdf](https://www.eltis.org/sites/default/files/sump-guidelines-2019_mediumres.pdf) (accessed 24 February 2020).

SEAI (Sustainable Energy Authority of Ireland), 2014. *Energy in Transport: 2014 Report*. Available online: <https://www.seai.ie/publications/Energy-in-Transport-2014-report.pdf> (accessed 3 January 2020).

SEAI (Sustainable Energy Authority of Ireland), 2019a. *Energy in Ireland 2019 Report*. Sustainable Energy Authority of Ireland, Dublin.

SEAI (Sustainable Energy Authority of Ireland), 2019b. Energy balances expanded 1990-2018, 21st of October 2019. SEAI, Dublin. Additional data received to 1990 from Martin Howley, personal communication.

Seto, K.C., Dhakal, S., Bigio, A., Blanco, H., Delgado, G.C., Dewar, D., Huang, L., Inaba, A., Kansal, A., Lwasa, S., McMahon, J.E., Müller, D.B., Murakami, J., Nagendra, H. and Ramaswami, A., 2014. Human settlements, infrastructure and spatial planning. In Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T. and Minx, J.C. (eds), *Climate Change 2014: Mitigation of Climate Change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 923-1000.

Seto, K., Davis, S., Mitchell, R., Stokes, E., Unruh, G. and Ürge-Vorsatz, D., 2016. Carbon lock-in: types, causes, and policy implications. *Annual Review of Environment and Resources* 41: 425-452.

SIMI (Society of the Irish Motor Industry), 2020. Motorstats: Passenger cars by segment. Society of the Irish Motor Industry. Available online: <https://stats.beepbeep.ie/> (accessed 30 July 2020).

Sims, R., Schaeffer, R., Creutzig, F., Cruz-Núñez, X., D'Agosto, M., Dimitriu, D., Figueroa Meza, M.J., Fulton, L., Kobayashi, S., Lah, O., McKinnon, A., Newman, P., Ouyang, M., Schauer, J.J., Sperling, D. and Tiwari, G., 2014. Transport. In Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., Seyboth, K., Adler, A., Baum, I., Brunner, S., Eickemeier, P., Kriemann, B., Savolainen, J., Schlömer, S., von Stechow, C., Zwickel, T. and Minx, J.C. (eds), *Climate Change 2014: Mitigation of Climate Change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 599-670.

TomTom, 2019. Traffic Index 2018. Available online: [https://www.tomtom.com/en\\_gb/traffic-index/ranking/](https://www.tomtom.com/en_gb/traffic-index/ranking/) (accessed 20 January 2020).

WHO (World Health Organization), 2018. Environmental noise guidelines for the European region. WHO Regional Office for Europe. Available online: [https://www.euro.who.int/\\_\\_data/assets/pdf\\_file/0008/383921/noise-guidelines-eng.pdf?ua=1](https://www.euro.who.int/__data/assets/pdf_file/0008/383921/noise-guidelines-eng.pdf?ua=1) (accessed 24 August 2020).

Wiener Linien, 2019. E-Mobilität. Available online: [https://www.wienerlinien.at/media/files/2019/factsheet\\_e-mobilit%C3%A4t\\_web\\_315122.pdf](https://www.wienerlinien.at/media/files/2019/factsheet_e-mobilit%C3%A4t_web_315122.pdf) (accessed 19 January 2020).

Windisch, E., 2019. Decarbonising passenger transport. Available online: <http://www.climatecouncil.ie/media/Dr%20Elisabeth%20Windisch%20-%20Decarbonising%20Passenger%20Transport.pdf> (accessed 21 January 2020).

Zhang, X., Chen, X. and Zhang, X., 2018. The impact of exposure to air pollution on cognitive performance. *Proceedings of the National Academy of Sciences* 115: 9193-9197. <https://doi.org/10.1073/pnas.1809474115>

